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Feasibility study on Wireless Sensor Technology for Agro Production Chains

Wireless Sensor System (WISENSYS)

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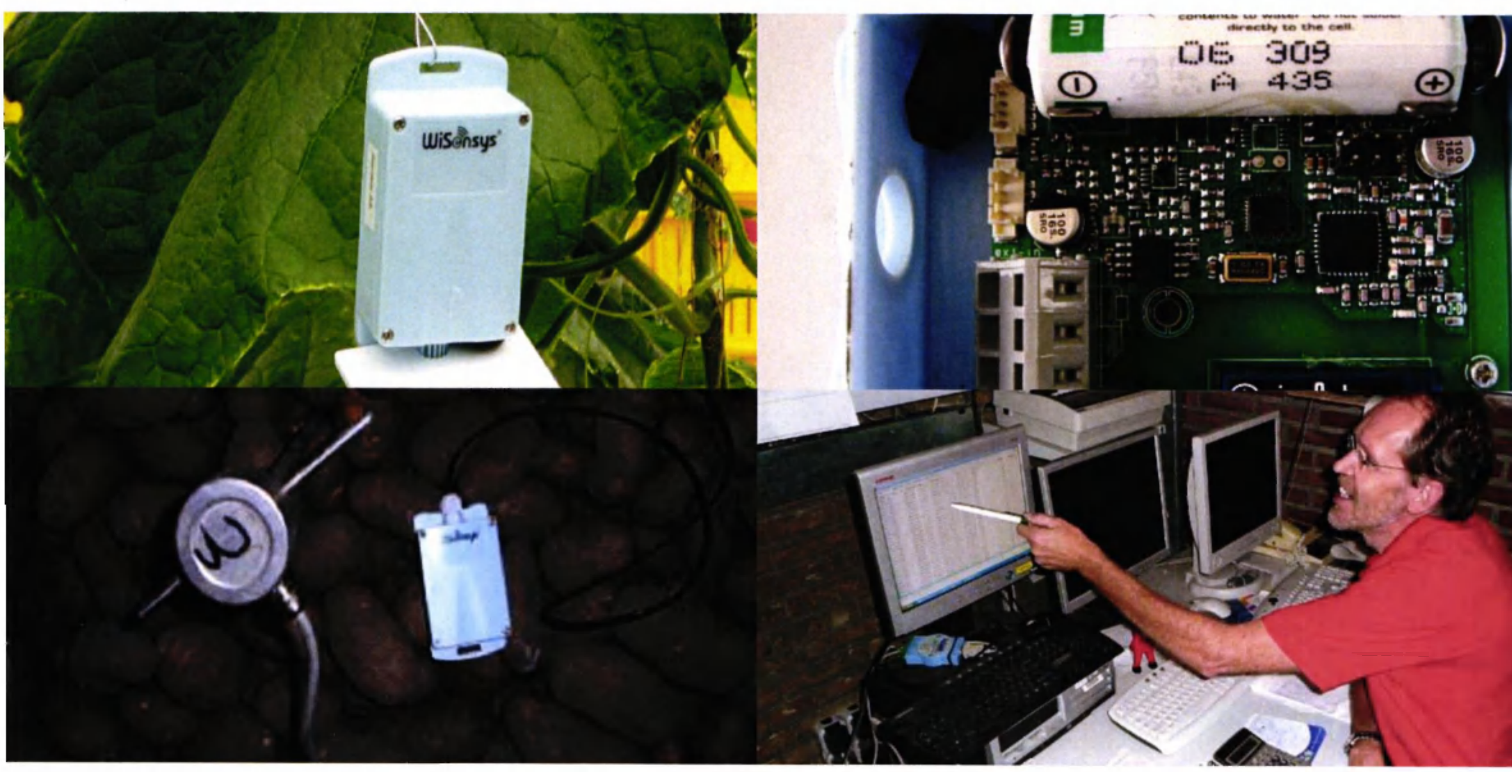

Fachhochschule Osnabrück
University of Applied Sciences

Note 523

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Wageningen UR Greenhouse Horticulture, Wageningen
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This project was performed for a consortium of companies, with EUCAN being the main contractor. The other contributing companies were: Wireless Value, T&M systems and Orbi-Solutions. The project was performed by Wageningen-UR Horticulture (project leader) is close collaboration with the University of Applied Sciences in Osnabrück. This project is supported with a grant of the Inspire and Innovate Programme, an Interreg III project funded by the Euregio Rhein-Wahl, the Euregion, the NRW bank (D) and the Ministry of Economic Affairs (NL).

Dit project is uitgevoerd in opdracht van een consortium van bedrijven, met Eucan als hoofdopdrachtver. De andere deelnemende bedrijven waren: Wireless Value, T&M systems en Orbi-Solutions. Het project is uitgevoerd door Wageningen-UR Glastuinbouw (projectleider) in samenwerking met de Fachochschule Osnabrück, met subsidie van Inspire en Innovate, een gezamenlijk initiatief van de Euregio Rijn-Waal, Euregion en het Ministerie van Economische Zaken (NL) en de NRW bank (D), in het kader van een Interreg 3 financiering.

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Summary

In agriculture production and food supply chains, nowadays on-line monitoring of environmental conditions is of great importance. Parameters to measure are for example air temperature and humidity, but many other parameters are monitored as well as f.i. rainfall, evaporation, soil moisture, nutrient content, stem diameter, and so on. This importance comes from the many strict rules and legislation on food safety (HACCP) and environmental rules (Water Framework Directive etc.), from the consumer wish to expect good quality (tasty) food products and on the other hand from an economical point of view from the producers to spill as less products as possible. This is especially for the high value agriculture food product markets (horticulture) but as well for the flower market (non-food). The tendency is to monitor in the whole production chain (from farm to fork) in a very dense way, in time and space.

The consortium, existing out of Eucan (Hengelo), Wireless Value (Emmen), and T&M systems (Tilburg), currently sells a product called WiSensys, which is a wireless sensor network. This product, which could fulfil in principle the needs for the above mentioned market, is currently being sold in another market. The consortium wishes to sell this, or an adapted product, onto a new market in agro production chains. By selling the existing technology into a new market (agro production chains for high value products) a number of questions arise whether the product fulfils the needs in these markets, but as well whether it is feasible to apply this technology. Further on forehand, it is not clear for which applications the technology could lead to an economically vial product. For this reason, the consortium consulted Wageningen University and the Fachhochschule Osnabrück to perform a technical and economic feasibility study on the introduction of the WiSensys technical concept onto the agro production chains market.

Due to regulations and the need to reduce environmental impacts, monitoring plays an important role in agro food production chains, a role which is growing ever year. Monitoring takes place on several spots in the chain (in open field production, greenhouses, storages, during transport, in distribution centres, in retail). The type of parameters to monitor, depend largely on the type of products (crop/flowers) or the phase or stage of the product. The market for this type of innovative products is rather wide. The problems associated with it, like the need for many wires and powering, and the lack of flexibility, drives people to look for alternatives like wireless sensors. This study focused on the evaluation of the market perspective and technical feasibility of the application of such a wireless sensor system (WiSensys) for high value horticulture food and flowers chains.

The scientific challenges for this study were the reliability and performance of this low-power wireless sensor network under the strong fluctuating RF propagation circumstances (damping) in agricultural environments, which influences strongly the reachable distance, especially in for instance greenhouses and buildings. This study therefore explored the reliability of the system under a number of practical situations. It further investigated the market perspective for the system. As such it tried to find those applications that would be the easiest to sell into the new market. Further, this study showed which enhancement or adaptations should be made to the current system, and which sensors are needed for the new markets. An estimate will be given about the expected market volume, and the potential partners and competitors will be mentioned.

The main conclusion is that the WiSensys system has large potential in agriculture, especially for temperature and relative humidity monitoring in greenhouses, and temperature monitoring in potato storages. Here, for the system with only minor adaptations, that there is a clear demand and a large market. No direct control, other than via manual intervention is needed and can be used next to other process monitoring systems. The system has advantages to wireless, dense sensor configuration, and reasonable indoor range. Compared to potential competitors, the WiSensys system proved rather well in these applications.

Greenhouses: The distance that can be covered in a greenhouse depends on the total amount of biomass inside the greenhouse and the placing of the individual sensors and the base station. For a high density crop distances were obtained reaching over 100m, providing that the pathway is only blocked by a limited amount of crop. For low density crops distances up to 250 m were obtained. The base station should have a high position, over looking all plants. Sensors can be placed inside the crop, but preferably near the top level of the plants. The transmission may

work through glass windows, but metal will block the signal drastically. The best thing is to optimise sensor placement by testing its performance at installation time. The sensor nodes should be protected from direct radiation by sun-light by placing them into a white box and/or placing a screen above the sensor, and an NKO type certificate must be requested for it. On the longer run the system might be expanded to become a water-, phyto- or micro-climate monitoring system by introducing new (external) sensors like: CO_2, plant temperature, ion concentration, O_2, pH, global radiation, air speed, soil moisture and EC. A large potential volume of sensors (up to 100.000) and even larger in a world-wide market is foreseen. Introduction of systems will be stepwise, larger new growers first and smaller growers with smaller systems next. Potential partners are Priva, Hogendoorn and Hortimax, which are entering the booming business for new horticulture production areas not only in Northern Europe but also abroad like in Mexico, China, Indonesia and the southern European countries.

Storages: Experiments showed a potential for the application of wireless sensors in potato storages. Low-frequency measurements for temperature and humidity are important for the quality and thus are major control parameters. Buildings seem to obstruct the direct signal enormously, but for the application taking care of sensor placement the application will work. The antenna should be kept upright, and typical distances in buildings are 80-90 m. For application in potato storages the system should be adapted mechanically. Preferably the long metal temperature sensor insertion needles must be fitted to the housing directly or via a cable. Due to the large market volume for potato storage the business volume is expected to be in the range of several thousands (best practice examples would be helpful for direct or indirect marketing). Intra-farm applications might go along with this (redundant temperature checking as for example). The market for mobile machines will be small in the beginning; opportunities might come up with successful implementations.

Other applications: A number of other potential applications with good market perspective are monitoring on mobile platforms, storage computing for silos, sensor activated control of distributed equipment in greenhouses, intra-farm equipment, transport monitoring and logging, phyto-monitoring, water, nutrient and fertilizer monitoring in substrates, potted plants or outdoor soil based crops for irrigation. These applications require however external sensors and the market and applications are rather dispersed, or they have a demand for on-line control. These markets should be entered in a second step. Partners for these markets can be found on the Hortifair (Amsterdam) and the Agritechnica (Hannover). The experiments with wireless sensors in agricultural equipment showed good results. The information needed for development or service purposes – having a look at the existing sensors – might be the temperature. For (mobile) outdoor applications (outdoor potato field) the mechanics of the sensors should be adapted to make them more robust against weather influences (dust, rain...) and vibrations.

Although world-wide there is a large trend towards the use of wireless sensors for agricultural production, in the two segments reported there are nearly no competitors. The applications that can be found are mostly in outdoor farming devoted to climate monitoring and irrigation scheduling. For greenhouse applications, only two applications were found (Sownet, Growlab).

The WiSensys system was tested in a greenhouse in Heerde (NL), at a cucumber grower which was very happy with the results. It would be wise to aim at a publication about this test in a grower magazine. The system could be sold by the larger greenhouse supplier companies like Priva, Hogendoorn Automatisering and Hortimax, which already have shown their interest. Regarding monitoring in storages, the larger potato farms (as for example in 'Emsland'), could be the ambassadors. The system was already tested at Brüggeman in Bramsche (Germany). So far wireless sensors in storage are not used. There is the opportunity to start with this business.

Foreword

Inspire and Innovate is a Euregion funding program that focuses on technological innovations in Food and Life Sciences, especially for new products, markets and organisations in the regions Euregion and Euregion Rhine-Waal. This project was established under this program with help from OostNV (Arnhem), being project leader of the Inspire and Innovate project.

The consortium, existing out of Eucan (Hengelo), Wireless Value (Emmen), Orbi-Solutions (Aalten) and T&M systems (Tilburg), currently sells a product called WiSensys, which is a wireless sensor network for monitoring applications in food storage. The consortium wishes to explore a new market for this product, especially in the agriĉulture and horticulture food production market. This goal fits well into the Inspire and Innovate themes on Food and Life Sciences especially for the sub-themes: Food Safety, Longer Shelf Life, Food and Flowers, Sensor Technology.

Early in 2007, via Inspire and Innovate, the consortium got in contact with two research institutes: Wageningen UR Horticulture and the Fachhochschule Osnabrück, which were able to assist its quest for a new market. It seemed both research parties were already working on similar topics, and from their point of view, in agriculture and horticulture, many needs for wireless systems were already observed. Through the funding by the Euregion all parties were able to set-up a project and work together on this goal during the summer and autumn of 2007.

The expertise in the consortium was perfectly balanced. The knowledge about markets and technologies from the small and medium enterprises were combined with the horticultural expertise from Wageningen-UR and the knowledge about technologies for storages and outdoor agricultural applications from the Fachhochschule Osnabrück. This combination, and on top the cross-border nature, made the project interesting, exiting and sometimes a little hard to organize. However, the underlying report, describes to a very detailed extend the work performed within the project. A lot of information for the consortium can be found there and I trust many answers and new insights will be found.

I hope the consortium finds the report useful for further exploring the agricultural market. I want to thank all partners for their help, support, critical questions during the workshops and especially the companies for their patience to wait for the final report under the pressure of a very competitive market.

Wageningen,

February, 22nd 2008

Jos Balendonck

1 Introduction

In agriculture production and food supply chains, nowadays on-line monitoring of environmental conditions is of great importance. Parameters to measure are for example air temperature and humidity, but many other parameters are monitored as well as f.i. rainfall, evaporation, soil moisture, nutrient content, stem diameter, and so on. This importance comes from the many strict rules and legislation on food safety (HACCP) and environmental rules (Water Framework Directive etc.), from consumers who expect good quality (tasty) food products and on the other hand from an economical point of view from the producers to spill as less products as possible. This is especially true for the high value agriculture food product markets (horticulture) but as well for the flower market (non-food). The tendency is to monitor in the whole production chain (from farm to fork) in a very dense way, in time and space.

The application of wireless sensor systems, therefore, has world-wide a large interest from both the scientific world as well as from companies. WiSensys, developed by Wireless Value (NL), is a wireless sensor system for monitoring and logging of readings from a number of different sensor types and for non time-critical control applications. It is sold world-wide through a network of dealers especially for application in restaurants (temperature) and food storage places (temperature and humidity). The partners in this project (the developer and dealer network) have noticed this interest and are convinced that there is even a larger market for the existing WiSensys product, especially in agriculture and horticulture. The existing system is the starting point for a feasibility study on new products in the market for agro productions chains based upon the existing technology. The fundamental aim of this study is access the technical and economic feasibility of the system through literature and market surveys, and quick practical evaluation, with the purpose to prepare the consortium for a possible research and development phase to build an actual new product for a new market.

To become able to sell a new product in a new market, induced by customers, the partners in this project want answers to the following questions:

- What are the possibilities (reliability, adaptations, expected life time, robustness, communication protocols) of the current system with respect to the RF-range of the current system under strong fluctuating circumstances in f.i. greenhouses, storage, transport and production?
- What new sensors should be connected to the WiSensys system to get a broader application of the WiSensys products?
- What market perspective (product market combinations, international partners) are there for the WiSensys system?

In agro food production chains, monitoring takes place on several spots in the chain (in greenhouses, storages, during transport, in distribution centres, in retail). The type of parameters to monitor, depend largely on the type of products (crop/flowers) or the phase or stage of the product. To have a multi purpose system, it is important that sensors can be replaced and installed quickly and easily.

The market for this type of innovative products is rather wide, but this study will focus only on applications for high value horticulture products (food and flowers). The most promising applications for the WiSensys system in the whole food chain from greenhouse, storage, transport, and distribution centres towards retailers should be evaluated and if needed new sensors should be identified.

The scientific challenges for this study are the reliability and performance of this low-power wireless sensor network under the strong fluctuating RF propagation circumstances (damping) in agricultural environments, which influences strongly the reachable distance, especially in for instance greenhouses. This study will therefore explore the reliability of the current system under a number of practical situations, it will suggest possible enhancement of the system, it will explore what type of sensors are needed for these new markets, and the ability to exchange multiple types of sensors in a rapid and easy way.

2 Materials and methods

The feasibility study is split up into a few phases. Its approach is based upon a commonly used way of generating new business, as for instance described in Kennisalliantie (2004). In this document, the process of business case development is split up into ten phases (see Figure 1), of which here, only the first eight phases are used.

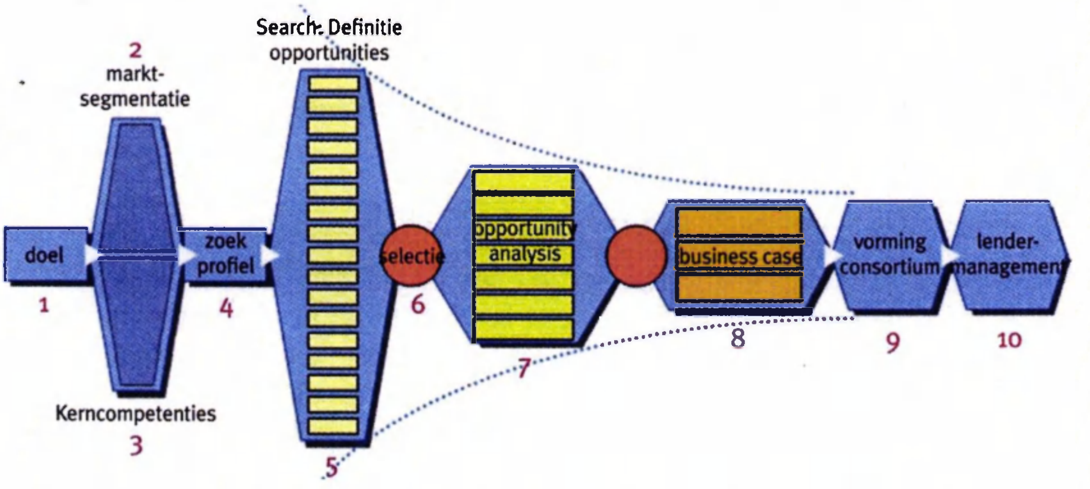


Figure 1. Stepwise approach for Business Case Development (Kennisalliantie Zuid-Holland, NL).

Step 1: Targets

A definition of the consortium targets.

Step 2: Segmentation of the market

Where is the most interesting market? What companies are active in which areas and where is knowledge available?

Step 3: Core competences

As a consortium, it is best to do that what you are good at. A market opportunity is only valuable when it fits well with your core-competences.

Step 4: Search profile

This search profile couples the markets with your core competences and leads to a description of sort of market opportunities you are looking for.

Step 5: Potential Product Market Combinations (PMC)

A list, including a brief description, of all opportunities that possibly fit the search profile.

Step 6: PMC selection

A selection of a limited number of PMC's based upon four criteria:

- Does it fit the core competences?
- Are the needed investments legitimate?
- How large is the business potential?
- Is it innovative, or do we expect a large competition?

Step 7: PMC analyses

Make an analysis of the most promising PMC's to a more detailed, but to a similar extend, so to make a further choice much easier.

Step 8: Business Case Analyses

Here for a few chosen PMC's a business case is worked out to a very detailed extend. Here answers should be given to the questions raised in step 6.

Step 9: Consortium Building

For one, or a limited number of, business case, a consortium must be defined and build. One should not ask: 'Who wants to join us', but rather ask the question: 'Who, and with what core competence, is needed?'

Step 10: Business Case Financing

The last step is to organise the financing (costs, funding) for the new business.

In this work these steps were incorporated into three sub-tasks executed by Wageningen-UR (WUR) and the Fachhochschule Osnabrück (FHO), and three workshops, attended by all partners (ALL). After the kick-off workshop (step 1), first a quick scan was performed to find possible product market combinations for the WiSensys product (step 2-5). These so called PMC's were presented in a first workshop, in which a range of PMC's were chosen for further focussing (step 6). Next in parallel, a technical feasibility and a market survey were performed, focussing on opportunity analysis and further selection of business cases (step 7-8). The results, as well as a draft report, were discussed during the final workshop. Based upon the outcome of this workshop, the final report was written. In more detail, these tasks can be described as follows.

2.1 Kick-off workshop

This was the first meeting between all partners (March 7th, 2007). In general the aims of the consortium were discussed, which resulted in an adapted and final project plan. The minutes of the workshop are given in Appendix 0.

2.2 Quick scan

In this phase the starting points were further specified and checked with the consortium partners. Based upon this, and through literature search, a number of potential product market combinations were defined. Through a literature search and interviews of specialists, for these PMC's, the preliminary implications for the WiSensys system were estimated for the high-value agro production chain (from grower to retailer), as well as for indoor (WUR), outdoor (FHO) as for delivery chain (FHO) applications. The result is a list of promising PMC's including its implications and an overview of the wishes and demands from an agriculture point of view. The results of the quick scan are presented in Chapter 3.

2.3 Second workshop

The acquired preliminary PMC-list was presented in a workshop (14th of June, 2007) where all partners were present. The list was discussed and based upon it; the consortium defined the general criteria to select a limited number of PMC's to be chosen for further detailed study of their technical and economical feasibility. Within the workshop the approach of the market survey and technical feasibility study were presented. The minutes of the second workshop are found in Appendix 0.

2.4 Technical Feasibility

The technical implications of the existing WiSensys system is further investigated through literature and desktop research, focussing on what possibilities it offers for application in the three selected PMC's. The following aspects are taken into account:

- What distance can be covered, and to what extend is this influenced by for instance crop growth and climate in the greenhouse, or other housing or location?
- What battery life time is requested for the application? In the WiSensys system the sensor is (may be) not powered by the WiSensys system. There are solutions to power the sensor externally.
- Is the existing packaging of the product sufficient, and what wishes exist (weight, colour, and size)?
- Based upon the existing products and protocols, are there sufficient possibilities to integrate the system with current monitoring and control systems? How is the system matching with existing systems?
- Is the current system sufficiently reliable (wireless connection) and what expectations do the applications have on this point?
- What sensors, or combination of sensors, should be connected to the system, and which sensors are still to be developed?
- Are there any specifications for security and the related certification of the system?
- Are there any rules or standards on RF-protocols (international) which the system should meet currently or maybe in future?

For the technical feasibility study some practical and simple experimental surveys were performed resembling applications for the selected PMC's. These experiments focussed on the stated technical questions to support the theoretical study.

2.5 Market Survey

This market survey will give answer to the question: 'What is the market potential of the WiSensys system for the 3 PMC's?' This study was done by short (telephone) interviews with representatives (end-users) from the specific markets, focussing on boundary conditions, product price and specifications. Furthermore competitors in the market segments were identified through literature search and desktop study (internet), focussing on the following aspects:

- Possibilities for delivering services which may lead to recurring revenues,
- International possibilities,
- Priorities for additions to the system which are needed and may lead to promising business cases, and
- Partners that are needed to generate the business cases.

2.6 Final Workshop

In a final workshop (1st Oct, 2007) all partners were assembled and discussed the outcome of the project. The minutes of this workshop are presented in appendix 0.

2.7 Final Report

The final draft report was ready in December 2007, later than expected. It was discussed during an (intended) meeting in Osnabrück. After that the report was amended and made final.

3 Quick scan

Before the Quick-scan, the starting points were further specified. They were checked with the consortium partners during the start-up and the 2nd workshop. Based upon these, and through literature search, a number of potential product market combinations are defined. Through a literature search and interviews of specialists, for these PMC's, the preliminary implications for the WiSensys system are estimated for the high-value agro production chain (from grower to retailer), as well as for indoor (WUR), outdoor (FHO) as for delivery chain (FHO) applications. The result is a list of promising PMC's including its implications and an overview of the wishes and demands from an agriculture point of view.

3.1 Definition of Aims

The aim of this study is to asses the technical and economical feasibility of the existing WiSensys system for the high value horticultural production market. A further purpose is to prepare the consortium for R&D actions in case the system should be adapted to make it suitable for this new market, so to maximise its economic profit.

3.2 Market Segmentation

Currently the WiSensys system is sold world-wide, but mainly in the Netherlands, German and Europe. There is only a dealer in Europe, but there is an ambition to seek a worldwide market. Products are sold in food chains, especially for applications where food safety is important, like for instance in restaurants and food storages (cooling) where temperature is an important parameter.

Wireless Value has the ambition to penetrate a new market with the current product especially the high value horticulture production chain market for fresh food (vegetables and fruits) and possibly flowers. Bulk crops like maize and cereals have lower priority within the scope of this study.

3.3 Core Competences

Wireless Value (Emmen, NL) is developer and seller of a wireless sensor system (WiSensys). It assembles the hardware from standard available sub-components, such as an RX/TX chip and the applied sensors. Wireless Value also develops and sells the software to operate the system. Its mission is to supply customers with systems for information gathering, specifically non time-critical applications and monitoring systems that pass information to an operator who is responsible for taking decisions and performing control actions. Wireless Value doesn't want to go into time-critical automatic control, which would imply that the system should have a far more reliable and fast response than it has at the moment. Wireless Value has a dealer network which is managed by Eucan (Hengelo, NL). Some of these dealers are involved in this study, like: T&M Systems (Breda, NL) and Orbi-Solutions (Aalten, NL).

3.4 Search Profile

The consortium defined the search profile as: 'wireless sensor systems for the high value (food and flowers) horticulture production chains'. Here this profile is further split up into:

- Secondary Supply Chain;
- Primary Supply Chain;
- Horticulture Production;
- Horticulture Delivery Chain.

For convenience purposes, the market for horticulture production is further split up into outdoor and indoor (greenhouse) production. In the delivery chain a further split can be made into the fresh market (food products) and ornamentals (f.i. flowers). This search profile is visualized in the following figure.

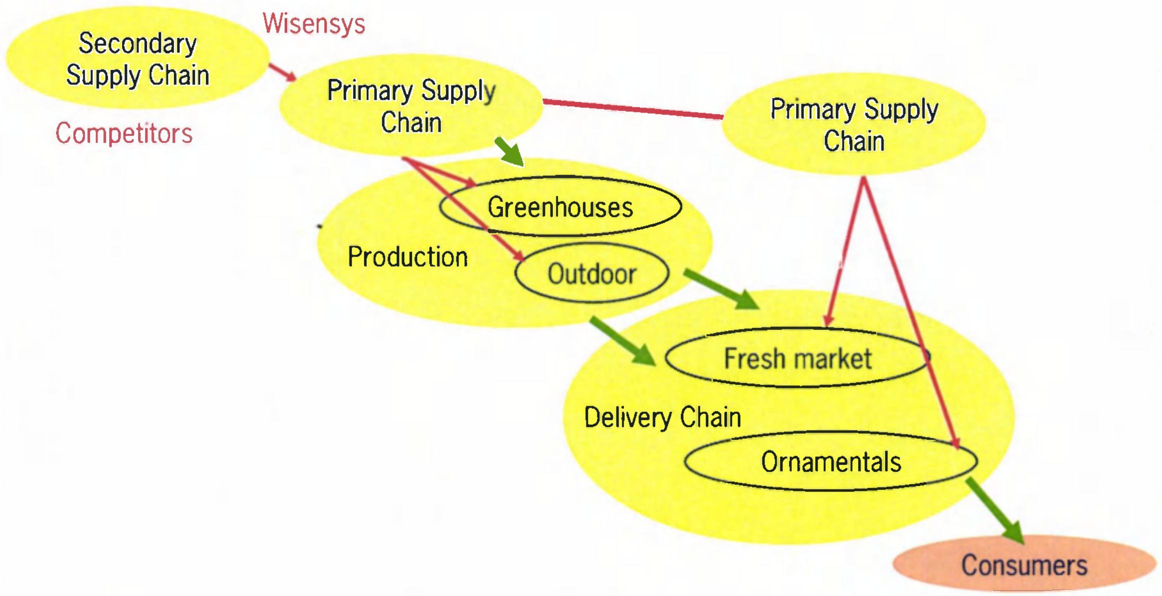


Figure 2. *Search profile for high value horticultural production chains. Customers are the end-users in the horticultural production chain, and are not considered being part of the chain.*

In view of the market for the WiSensys products, the chains are organised according to the line: seeds, grower, trade, and retailer. Each segment has its own market strategy and quality strategy. Growers would like a complete and turn-key system without bothering too much with details. Seed companies would like guarantees about the data. ISO is important in trade. It may lead to different propositions and value packs for the several segments. In the following paragraphs these markets will be described further, following a chapter containing the potential product market combinations identified according to the defined search profile.

3.5 Production Chains

Potential users of wireless sensor technologies can be found in horticulture production, which are growers working in greenhouses or on open fields (outdoor). These growers are supplied through specialised companies (the primary supply chain), selling a broad range of products. It is unlikely that the WiSensys system itself will be sold by the WiSensys consortium to individual growers, so here no actual PMC's are found. However, a description of the sector is valuable for the final market survey.

According to the Productschap Tuinbouw, the whole horticultural sector, especially greenhouses, needs to innovate. In a special innovation program for flowers and food, six areas are defined as key issues:

- Connection with the markets and concept development,
- Health and well being,
- Chain management,
- Sustainable and large-scale horticultural clusters,
- Application of Green Genetics, and
- Intelligent production.

Besides these general innovation topics, environment (energy and water), labour and product quality are important factors for the growers themselves. Within all these topics, many chances to apply wireless sensing systems can be found. A large variety of food and flower products are produced by growers. An inventory of all production groups can be found on the PT-website (www.tuinbouw.nl), or the WUR (http://www.lei.wur.nl/). For our convenience, we split-up horticulture into two areas:

- Greenhouse production, and
- Open field production

Next these parts of the chain will be described, including their primary suppliers.

3.5.1 Greenhouse production

Crop production and production systems world-wide

A good introduction on greenhouse production world-wide is given by Athanasios P. Papadopoulos; Dominique-André Demers (2007). Here, parts of this paper are being used.

Plant cultivation is influenced by various factors, such as soil quality, water availability, and climatic conditions. Techniques have been developed either to adapt food crops to their environment, or to adjust the environment (for example, temperature, nutrient supply) to meet plant needs. Practical (passive) means of modifying the environment surrounding the plants have involved methods such as the use of windbreaks, mulches, plant or row covers, and cold frames. However, the only method of food crop production that makes use of control of the environment is greenhouse production, also referred to as controlled environment agriculture (CEA). With the use of a greenhouse, it is possible to cultivate food-producing plants in locations and at times when climatic conditions would adversely affect them or even prevent them from growing. The term 'greenhouse' is defined as a structure covered with a transparent or translucent material, in which environmental conditions can be modified or controlled, for the cultivation of plants, including tunnels.

Today, food production in greenhouses can be found in all continents. Most popular food crops grown in greenhouses are tomato, cucumber, and sweet pepper. Other greenhouse grown vegetables include watermelon, muskmelon, summer squash, zucchini, lettuce, eggplant, snap beans, celery, cabbage, radish, Welsh onion, and asparagus. Fruits such as grapes, strawberry, banana, pineapple, papaya, orange, mandarin, cherry, and fig, as well as culinary and medicinal herbs, are also grown in greenhouses.

Table 1. Main food and flower products in the Netherlands (LEI, 2006).

Crop Types	Main Crops	Production Area (ha)
Vegetables	Tomatoes, Pepper, Cucumber, Aubergine	4.304
Cut-flowers	Roses, Chrysanthemum, Lily, Gerbera	3.093
Potted plants	Kalanchoë, Phalaenopsis, Anthurium, Ficus, Dracaena, Roses	1.386
Other flowers	Viola, Pelargonium, Petunia, Osteospermum, Lobelia	902
(Ornamental) trees and not-potted plants	Several	404
Fruits	Strawberry	293
Mushrooms		70

The main greenhouse covering materials are glass and polyethylene (PE). Glass-covered greenhouses are concentrated mainly in northern Europe and North America. The low cost of the PE greenhouse is the main reason for its high popularity, especially in developing countries. Greenhouses come in many styles and sizes, from the original houses with minimal climate control (furnace and vents) to the modern 10-ha or more, multi-span greenhouses with high-tech climate controls (sophisticated and powerful heating system, CO_2 enrichment, evaporative cooling pads, exhaust fans, roof vents, thermal/shade curtain, computer controls, light sensors). Most sophisticated greenhouses are generally found in the developed, northern countries.

The degree of environment control needed depends on various factors. The first factor is the location of the greenhouse (local climatic conditions). Northern regions are characterized by cold winters and warm summers, which requires a high-tech greenhouse. In regions such as the Mediterranean (Spain, Italy, Morocco, Greece), the mild winter climate does not require the use of powerful heating systems, and low-tech greenhouses are sufficient for winter production. However, this may not provide satisfactory temperature control to grow plants during very hot summers. Optimal growing conditions further differ from one species to another, and the production schedule also affects the level of environment control and thus the level of technology.

Economic development also plays a role in the level of technology used in the greenhouse. In developing countries, growers may not be able to afford the most sophisticated equipment, and may lack technical expertise and technical support.

Table 2. Estimated greenhouse area (ha) and important food crops grown in greenhouses worldwide.

Country	Total area	Food crops area	Hydroponic	Important food crops		
China	360 000	(-)[z]	140[y]	Cucumber (-)[x]	Tomato (-)[x]	Sweet pepper (-)[x]
Spain	55 000	> 50 000	4 000 (10)	Melons (-)	Tomato (-)	Sweet pepper (-)
Japan	52 571	43 950 (84)	655 (1.5)	Tomato (15)	Cantaloupe (13)	Strawberry (13)
Italy	26 000	21 000 (81)	400 (1.9)	Tomato (-)	Zucchini (-)	Sweet pepper (-)
Korea	21 061	(-)	(-)	Cucumber (-)	Chinese cabbage (-)	Tomato (-)
Western North Africa[w]	11 400	> 7 900	(-)	Tomato (47)	Sweet pepper (25)	Cucumber (8)
Turkey	10 800	9 000 (83)	(-)	Tomato (-)	Cucumber (-)	Melon (-)
The Netherlands	10 800	4 335 (40)	2 895 (72)	Tomato (30)	Sweet pepper (23)	Cucumber (16)
France	9 100	6 500	(-)	Tomato (-)	Cucumber (-)	Strawberry (-)
United States	5 000	300 (6)	300 (100)	Tomato (-)	Cucumber (-)	Lettuce (-)
Greece	4 620	3 790 (82)	60 (1.6)	Tomato (-)	Cucumber (-)	Eggplant (-)
Middle East[w]	4 300	3700 (86)	(-)	Tomato (65)	Cucumber (21)	Sweet pepper (10)
Germany	3 300	(-)	(-)	Tomato (-)	Cucumber (-)	Lettuce (-)
Belgium	2 250	1 600 (71)	850 (53)	Tomato (38)	Lettuce & herbs (19)	Cucumber (5)
United-Kingdom	1 600	(-)	(-)	Tomato (-)	Cucumber (-)	Lettuce (-)
Canada	1 470	756 (51)	600 (80)	Tomato (56)	Cucumber (24)	Sweet pepper (16)
Arabic peninsula[w]	(-)	1930	(-)	Cucumber (53)	Tomato (28)	(-)
Eastern North Africa[w]	(-)	1700	(-)	Cucumber (38)	Sweet pepper (34)	Tomato (20)
Mexico	(-)	350	17.5 (5)	Tomato (-)	(-)	(-)
Brazil	(-)	(-)	50	Lettuce (-)	Arugula (-)	Watercress (-)

[z] *Value in parenthesis: percentage of greenhouse area used for food crops in each country, calculated over total greenhouse area; (-) = unavailable data.*

[y] *Value in parenthesis: percentage of greenhouse area with hydroponic systems in each country, calculated over greenhouse area for food crops; (-) = unavailable data.*

[x] *Value in parenthesis: percentage of greenhouse area for major crops in each country, calculated over greenhouse area for food crops; (-) = unavailable data.*

[w] *These regions include the following countries (in order of importance of their greenhouse industry): Western North Africa: Morocco, Algeria, Tunisia; Eastern North Africa: Libya, Egypt; Middle East: Jordan, Lebanon, Syria; Arabic peninsula: Saudi Arabia, Kuwait, United Arab Emirates, Iraq, Bahrain, and Qatar.*

Greenhouses in desert regions

Although greenhouses were developed in northern regions as a means of protecting crops against cold temperatures, and are therefore generally associated with cold climates, they are also used in arid regions such as Saudi Arabia. In such regions, the objective of the greenhouse is to protect plants from the excessive solar radiation and temperature, and to prevent excessive water loss by plants (especially since water resources are generally limited in those regions). Therefore, technology in greenhouses in these regions is directed toward cooling.

Artificial lighting

In northern countries, high-tech greenhouses can provide optimal growing conditions (temperature, humidity, carbon dioxide) for vegetable crops even during the coldest winter months. However, even with excellent climate control, yield and quality of crops grown during these months are low due to the low light level available. Research has shown that it is possible to produce good yield of high-quality produce during the winter months by using artificial light to supplement the natural radiation. The most common artificial lighting is the high-pressure (yellow coloured) sodium lamp. The high cost of electric energy in many regions is the most important factor preventing an increased use of artificial light. Current research indicates that modern LED-lights may be used as lighting in greenhouses.

Production Systems

Growing in soil

Since the early days of greenhouses, plants have been grown in soil or in soil-filled containers. The first technique for fertilizing plants, which is still in use today in organic production, was the use of manure. Today, fertilization of plants can also be accomplished by incorporating chemical fertilizers in the soil, or by distributing fertilizers dissolved in water (so-called fertigation) to plants with a drip (trickle) irrigation system. Intensive and repetitive cultivation of crops on the same soil generally results in a degradation of soil properties and fertility. Salt accumulation may be another problem in soil cultivation. Incorporation of manure, compost, and other organic materials into soil can be used to improve its structure and replenish its fertility. However, ensuring perfect fertilization of plants grown in soil is still a difficult task. Furthermore, intensive and repetitive cultivation of crops on the same soil can also result in insect or disease infestation. Soil replacement and soil fumigation are two solutions, but the first technique is expensive and the second is not always successful. Greenhouse production in soil is still used widely.

Table 3. Estimated area (ha) of protected crops per region and type of structure.

	Plastic	Glass	Total
Asia	440 000	3 000	443 000
Mediterranean	97 000	8 000	105 000
Americas	15 600	4 000	19 600
Europe*	16 700	25 800	42 500
Africa + Middle East*	17 000	-	17 000
Total	586 300	40 800	627 100

* *Excludes European countries on the Mediterranean Sea.*

Growing without soil

In order to better control fertilization for optimizing plant growth and yield, and also to avoid the problems occurring in soil, growing systems that do not use soil (soilless) were developed for the cultivation of greenhouse crops. These soilless systems can be classified in two groups: liquid (water) and solid (artificial substrates that are either inorganic or organic). Systems using water as a growing medium are the nutrient film technique (NFT), deep flow technique

(DFT), and aeroponics. Common inorganic media are Rockwool, vermiculite, perlite, and clay pellets. Organic substrates are peat, coconut coir, sawdust, and straw. Inorganic and organic substrates are usually contained in bags, and plants are irrigated with a complete nutrient solution distributed by a drip irrigation system. The excess of nutrient solution can either be allowed to leak into the ground or is recuperated and recirculated (after treatment) to plants. In liquid systems, plant roots are continuously exposed to nutrient solution, which is not leaked into the ground.

Growing methods using artificial substrates or water are known as soilless culture or hydroponics. Hydroponics is literally defined as the growing of plants in water, but the plants are actually grown in a complete nutrient solution. Ideally, the term hydroponics should be reserved for water culture, and the term soilless culture for plant cultivation on artificial substrates. In practice, the terms hydroponics and soilless culture are used indiscriminately to describe water and substrate-based systems.

Although official statistics are unavailable, hydroponic systems are known to be used extensively for food production in greenhouses. The most popular soilless medium for hydroponic vegetable production is Rockwool. The nutrient film technique is also often used, but to a much lesser extends than Rockwool. In some regions, the availability of low-cost materials may provide alternative substrates. For example, in British Columbia, sawdust, a residue of the large forestry industry, is commonly used as a substrate. Both aeroponics and DFT remain in little use today.

Insect and Disease Control in Greenhouses

One objective of hydroponics is to avoid insects and diseases that may occur in soil. In a soilless culture system, such as Rockwool, it is easy to remove infected plants. However, spread of diseases can occur very quickly in systems where nutrient solution is recirculated. Methods such as filtration of the nutrient solution, and disinfection with ozone or ultraviolet light, have been developed to eliminate pathogens that may be present in the nutrient solution. However, these methods are often expensive and not completely effective.

Greenhouses are used to create and maintain an environment ideal for plants. However, this environment is often favourable for insects and pathogens too. In the past, the control of insects and diseases in greenhouses was accomplished with the use of pesticides, but over time both insects and diseases have developed resistance to such pesticides, while consumers have begun to demand pesticide-free produce. Biological agents are now used to control whitefly, thrips, aphids, and two-spotted spider mite in greenhouses; few reliable biological agents are currently available for the control of diseases.

Research on Greenhouse Food Crops

In countries or regions where greenhouse production is an important industry, government and universities are generally involved in research on greenhouse production. The general objective of the research is to improve yield and quality of produce and profitability of production, by investigating all aspects of greenhouse production: greenhouse design and covering materials, growing methods, environment controls, substrates, plant nutrition, plant pathology, and insect control. Grower associations may also be involved in the development of research priorities, and may contribute financially to the expenses of research.

Due to the presence of a large and technologically advanced greenhouse industry in the Netherlands, the most notable research institutions are found there. The Research Station for Floriculture and Glasshouse Vegetables (under the Ministry of Agriculture, Nature Conservancy and Fisheries) has five sites. The other important Dutch institution is the University of Wageningen.

In the United Kingdom, Horticulture Research International (HRI), the largest horticultural research establishment in the world, maintains an active research program on greenhouse crops and provides its services (from fundamental research to technology transfer) to research councils, government departments, growers, and commercial industries, in the European Community (EC) and other countries.

In the Americas, the Greenhouse and Processing Crops Research Centre (GPCRC; Agriculture and Agri-Food Canada) is the largest research facility specializing in greenhouse vegetables. The GPCRC is a leading member of the Canadian Network for Greenhouse Vegetable Research.

Japan, Spain, and Israel are some of the other countries with important research programs in horticulture, including greenhouse food production.

The International Society for Horticultural Science (ISHS) is an international organization of horticultural scientists, which aims at promoting research in all branches of horticulture, including greenhouse food production. Within the ISHS, there are various commissions and working groups related to greenhouse production.

Future of Greenhouse Food Production

As the world population continues to increase, and more agricultural land is lost to urban development, intensive food production in greenhouses may play a more important role in food production. Furthermore, improving economic conditions in developing countries and an increasing preoccupation with health and nutrition will increase demand for high-quality food products. Through controlled climate and reduced pesticide use, greenhouses can meet this consumer demand. Foods with improved health characteristics or containing nutraceuticals (substances with pharmaceutical or health-beneficial properties that can be extracted or purified from plants) can be grown pesticide-free in greenhouses.

Sensors and actuators in greenhouses

Modern crop production in greenhouses is based upon sensors activated control of climate (heating, ventilation, screens and CO_2) and water and nutrient supply, which are in fact the above and underneath ground environments for the plant. This is depicted in the next figure. These control systems are embedded into the full management system of the grower, as given in next following picture. Real-time information gathering is very important for the grower. Therefore, many sensors are installed in greenhouses. A number of parameters however, can not be measured in a direct physical way. For this, nowadays, soft sensors or models fed with data from physically measurable data are applied (see next figures).

The above mentioned controllers are in fact embedded into a few higher level controllers, which set the set-points for these low-level controllers. The first next higher level (control level) is driven by a plant and climate model. Then the next higher level is the 'planning level' which observes the growth of the crop and the forecasted weather, and based upon scenario planning it takes decisions. The highest level of control is the grower who takes decisions on which plants to grow and the auction prices he anticipates.

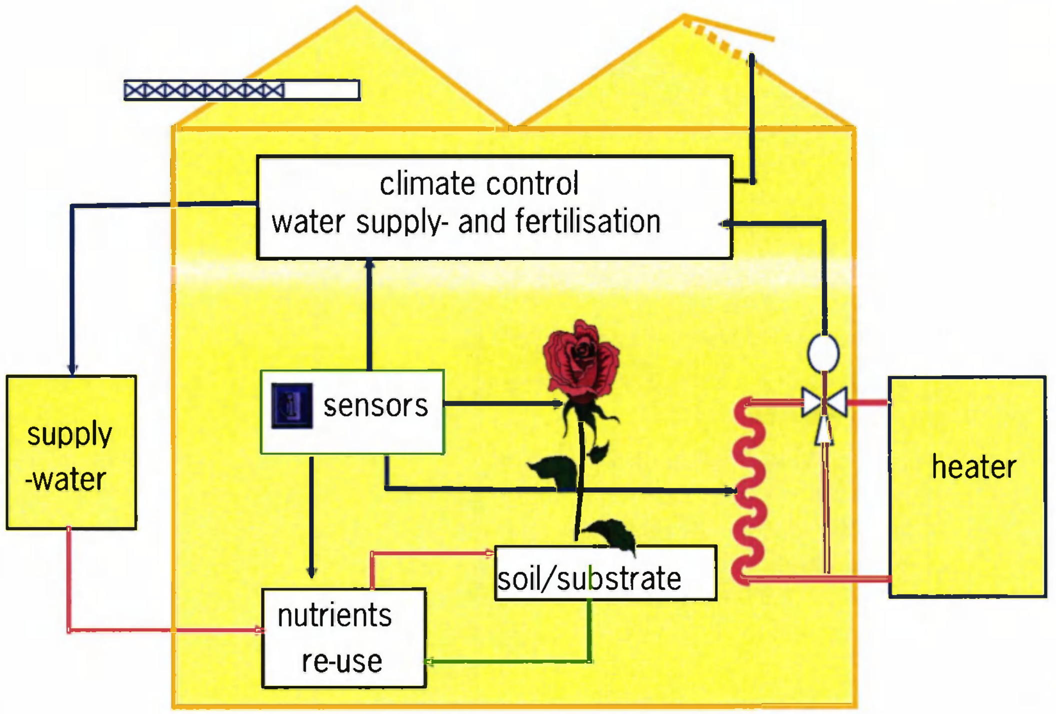


Figure 3. A greenhouse climate controller.

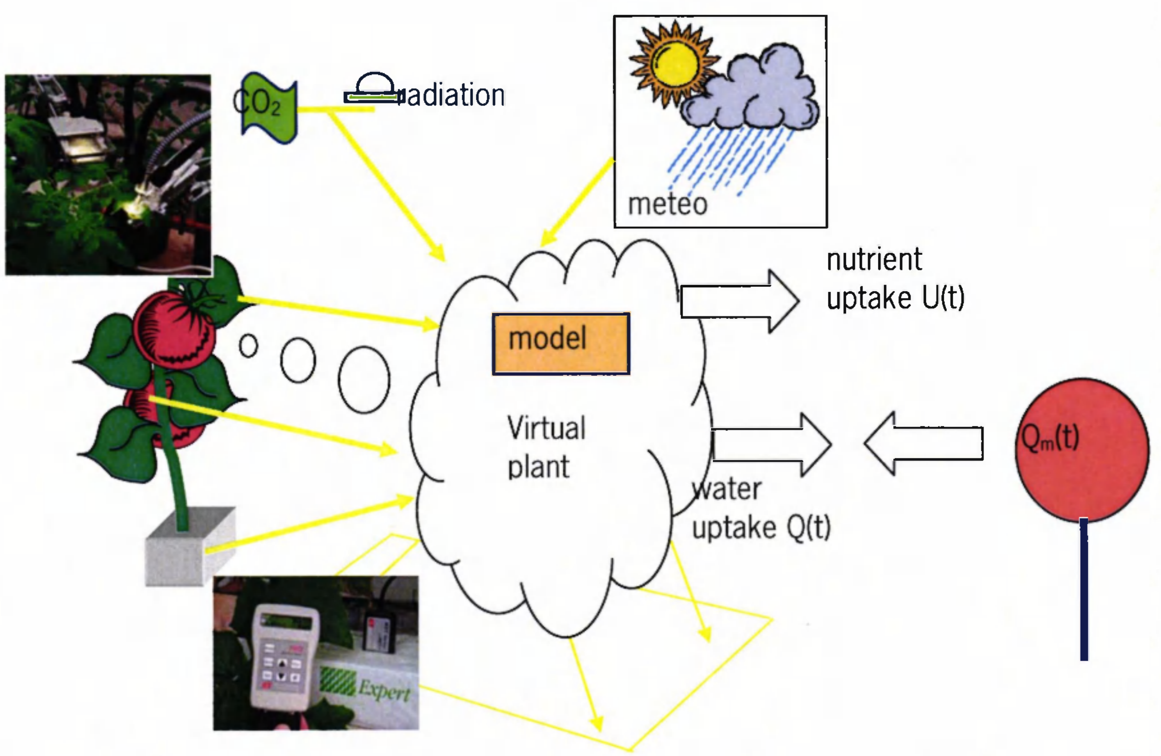


Figure 4. Non-physically measurable data is obtained through a 'Soft-Sensor' or a 'Virtual Plant Model'. Inputs to these models are climatic, plant or substrate sensors.

3.5.2 Open field production

This chapter is dealing with outdoor crop production in the field. The plants growing in the field are not as sensitive against climate changes as the ones cultivated in greenhouses. Primarily, these plants are seeded, treated and harvested by agricultural machines. Therefore, tractors with different kinds of accessory equipment or self-propelled machines are used:

- Soil cultivation machines
- Drilling machines
- Harvesting machines
- Pest management machines
- Fertilizer machines

The total worldwide production volume of agricultural machines is about 47 billion €, where 42 % are in the EU (Yearbook Agricultural Engineering, 2007, vdma; vdi-meg, KTBL, ISBN 978-3-7843-3438-7). Thus, this is a dominant market with strong links to technological companies in the field of sensors (strongly growing) as well as to farmers.

These machines are equipped with several sensors. Sensors are, for instance, used to guarantee an evenly distributed seeding of the drilling machine or to check the nitrogen level of the plants to perform an individual fertilization of different areas. Most of these sensors are connected to a bus system to be able to communicate with a central control unit or a user interface.

In Germany, one half of the acreage is used by crop and another quarter is used by fodder plants, maize, grass and Lucerne. After the harvesting of the plants, most of them are brought to silo storages before they are used. The rest of the acreage is used for the cultivation of canola, beets, potatoes and a little part of the acreage is used for vegetables. The storage of these products is more complicated then the storage in a silo. The reason for this is that these products are primarily put in box storages or bulk storages to be able to have a constant climate in the storage building. This is especially important for the storage of potatoes. Potatoes are very sensitive against:

- Pressure
- Changing temperature and humidity
- Fast cooling and heating
- Too high carbon nitrogen in the air

Because of this it is important to be able to control the climate in the storage building. Table 4 shows an overview of the different acreage sizes used by the different products. It also shows how high the earnings for the different products are. Figure 5 gives an overview of the total production of f.i. potatoes in Germany.

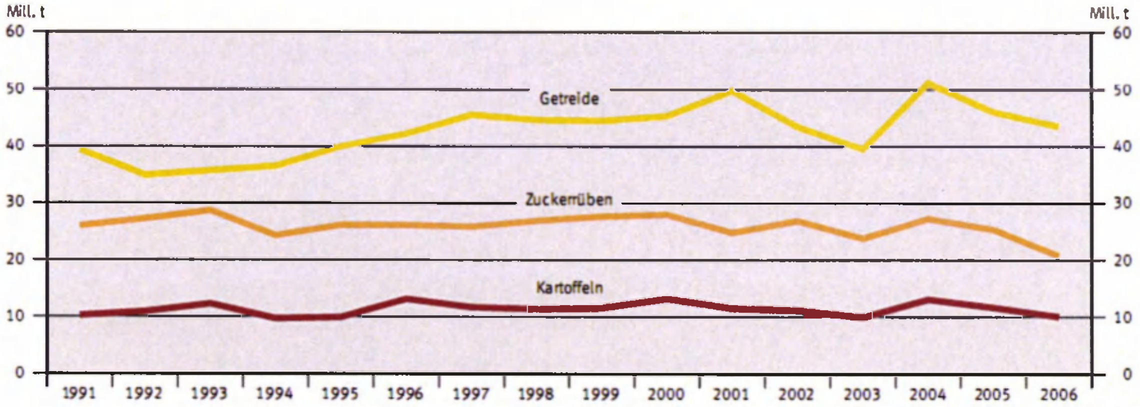


Figure 5. Total production of potato, in Germany.

Table 4. Arable farming in Germany (total: 11.860.000 ha).

	Acreage in [1000 ha]	Yield per hectare [dt]	Earnings [1000 t]
Cereals	6702	ca.65	43563
Beets and Beetroots	1430	ca.37	5291
Feed plants (maize)	1345	394	52993
Feed plants (grass, alfalfa)	575	ca.78	4485
Sugar beets and beet	362	583	21105
Potato	265	410	10865
Legumes	107	32	342
Vegetables on the Free Country	107	89-553	3210
Others	967		

In the following section, the amount of farms needing storage systems will be shown. Therefore, only the storage of potatoes will be taken into account.

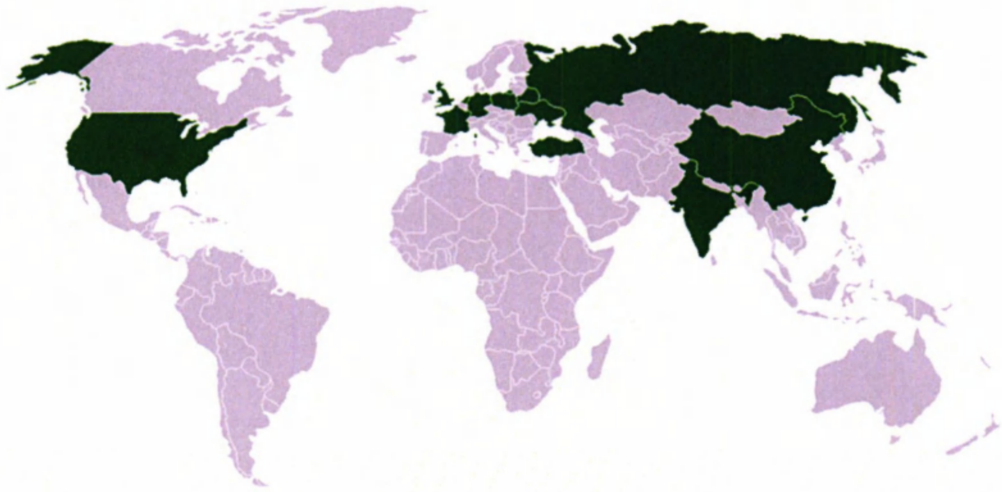


Figure 6. States with the highest percentage of potato production in the world (ca.73%).

Figure 6 shows the main areas for the potato production in the world. By the leading potato producing countries, an amount of 195 million tons has been produced in the year 2005, which is about 73% of the worldwide potato production.

Table 5. Leading potato producing countries (in million tons).

Country	2005	2003	2002	1995
China	73	68	70	46
Russia	36	37	33	40
India	25	25	24	17
Ukraine	19	18	17	15
USA	19	21	21	20
Germany	11	10	11	11
Poland	11	14	16	25

The area of potato cultivation in Germany is decreasing year by year. From 1992 to 2007, the area size changed from 360000 ha to 272600 ha. But the harvest in the year 2007 with an amount of 10 million tons is still the same as the one in the year 2006. The harvest per area has vacillated within the last year, but it didn't change a lot upwards or downwards [rmx].

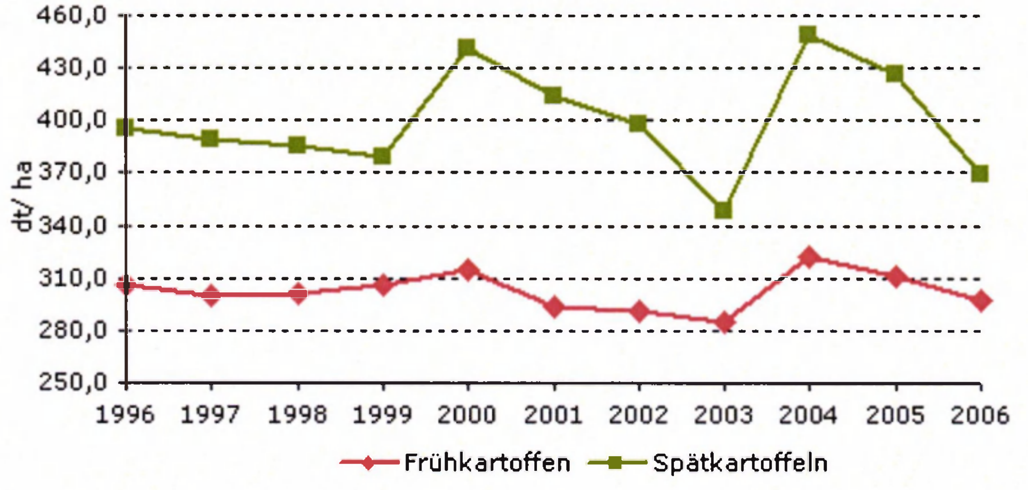


Figure 7. Development of the harvest per area of potatoes from 1996 to 2006 in Germany [bmelv].

In this year (2007), 63900 farms in Germany produced potatoes. The area of these farms is fluctuating from 0 to 100 ha (see Table 6).

Table 6. Amount of farms regarding the area size.

0-2 ha	900
2-5 ha	8400
5-10 ha	10100
10-20ha	12600
20-30ha	6200
30-50ha	8800
50-100ha	10400
100-...ha	6400

All these farms have to put the potatoes in the storage for a certain time. The storage time depends on the potato type and the type of storage available. The longer the potato is in the storage, the higher the price for it gets.

Table 7. *Potato usage.*

Usage
ca. 25% for human consumption
ca. 25% for starch and alcohol
ca. 40% as feed for animals
ca. 10% used for salads

The advantage of using wireless sensors in the storage is that they can be setup quickly and that they do not have disturbing cables, which might limit the positioning. The position can be changed without any problems. With the usage of these sensors it is possible to save several meters of cable that might damage the potatoes while removing from stock.

Most of the farmers have to put their products in a storage which makes them to customers oft he companies in the field of storage technologies. If these companies would use the products by WiSensys, then the farmers are customers of WiSensys as well.

The quality of the potatoes depends in an extremely high degree on how they have been treated during the time of storage. This means that the price is strongly related to the way storing the potatoes. That is why it is very important for the farmer to check the climate within the storage building to keep the quality of the potatoes at a high level. The result of this is that the farmer will lose money if he is not monitoring the temperature and humidity during the time of storage. Because of the changing conditions within one huge storage building used for the potatoes it is also of a high importance to use more than one sensor for this task. The usage of several sensors would enable the farmer to check the climate in different places of the room. With an amount of f.i. 10 million produced tons of potatoes in Germany in the last year a huge market for the WiSensys sensors is available.

The second survey is related to market of agricultural machines and transportation. This market has got double-digit rates of growth in the last years. For this market it could be possible to use sensor for the logging applications. To be able to use the sensor for logging the temperature or the humidity while driving, no change has to be done to the hardware. The logged data can be, for example, analyzed afterwards to check the climate during the last trip. This could be an easy way of accessing a huge market with lots potential customers and a high growth rate.

During the Agritechnica 2007 companies in the fields of storage and agricultural equipment had been interviewed for this market survey. These companies have been asked about their interest of integrating WiSensys sensors into their product or to sell them as a piece of their product range. The result is that some of the companies, in the field of storage, are very much interested in integrating the WiSensys sensors into their products. Therefore, the protocol of the sensors needs to be adjusted to match the exiting protocols of the control systems. The companies in the field of agricultural machines are only interested in using the sensors during the development of new product. The complete overview of the interview can be found in the appendix.

Having a look at the future, it is estimated, that agriculture technologies push the wireless sensor implementation. Aspects are energy, automation, precision farming and field robots [wang].

3.6 Horticulture Delivery Chains

Delivery of the products from primary production is arranged in several separated sub-chains. Nowadays, these chains are organised in such a way that they are kept as short (in time) as possible. For plants it takes generally a week, however Flora Holland claims that the path from grower to user takes only one day. For daily fresh vegetables this might be 1-2 days. From grower to end-user, products only pass 2-3 distribution centres, and the auction is often by-passed physically by making products only virtually available at the auction. In some cases even the products go directly from grower to the processing industry or end-user, in such occasions where growers have made individual or collective agreements (growers consortia are f.i. FreshQ, VDN) with the larger buyers (f.i. Albert Heijn, Ikea, Gamma). About 50% of the products are brought to the auctions.

Looking at the chain we see that the physical (product) flow normally goes a separate path from the information flow (ownership). The latter is being done fully by computer and general organised by one central chain-manager.

Between growers and end-users a number of parties are active:

- Growers and growers consortia
- Transporters
- Importers/exporters
- Storage houses
- Auctions
- Processing companies (fresh market)
- Wholesale
- Distribution Centres
- Retail

About 70-80% of the total production in the Netherlands is exported. Most of the food, flower and plant products are transported via road, apart from the cut-flower market that makes use of airplanes. The main export market is Europe with Germany being the largest buyer of products from the Netherlands. For this transport mostly standardizes trolleys are used, like the Euro and Danish containers.

3.6.1 Vegetable and fruit chains

The Netherlands are world known for their exporting of fresh vegetables. This is rather remarkably since only 0.5% tomatoes, 1.3% sweet peppers and 1.1% cucumbers of the world production are produced in the Netherlands. More than 80% of these products are exported to foreign super markets. Holland and Spain are the main suppliers for price-oriented German and quality oriented British supermarkets.

Greenhouses

Most of the greenhouse products (tomato, cucumber, peppers) are sold in the fresh market. Sorting and selection is being done at the grower or special grower collective organisations. Products are being delivered to the chain in standard (blue) crates, or packed in smaller packages, to be more convenient for the end-user.

Open field production

Vegetable products produced in the open field are either sold in the fresh market or go to the processing industry. For the fresh market products are sold in standard blue crates and are barely processed, maybe cleaned a little and packed. Traditionally vegetables and fruits that should be consumed on a much later time instance are conserved in the processing industry by deep-freezing, tin-cans or glass pots. Nowadays for the fresh market (convenient foods) vegetables are also pre-cut, cleaned and packed, which is being done in special processing companies.

Auction, wholesale and import-export

Import and export is the next chain in the whole delivery chain. The total number of traders (NL) is more than 1400, a large number compared to the number of supermarkets. In 2000 a total 170 wholesalers had a turn-over of more than 2.5 Billion tons of Dutch product, of which 12 of them exported more than 50% of this volume. The main port Rotterdam with a special terminal for fresh fruit strengthens the position of these traders. They have the possibility to offer a large variety of products, including citrus fruits and other exotic products year around. Re-selling has become an important business and Dutch traders more and more trade foreign products. In the Netherlands, the Greenery is the largest market organisation for vegetables, fruits and mushrooms. The next in row are Bakker Barendrecht and Haluco. Despite of their size, even in the European context, their turn-over in fruits and vegetables is still lower than that off the Dutch supermarkets.

The Greenery was formed several years ago by fusion of a number of smaller auctions, by the time the larger supermarkets started ruling the common market. It has an annual turnover of 1.7 billion Euros and has sites in Barendrecht, Breda, Bleiswijk, Maasland, Nieuw-Amsterdam, Zaltbommel and Venlo. About 2000 growers deliver their products to the Greenery directly, based upon contracts. Due to this large number it is very difficult to maintain a standard product quality. Therefore, the Greenery has set-up a very strict quality system. Year around, the Greenery can assure the delivery of a large product assortment to the larger retailers in Europe, North America and the far East, through import. Other important target groups are the wholesale, catering and processing industry.

Another important competitor in the market in the Netherlands is the trade organisation ZON (Zuid Oost Nederland) located in Venlo. Furthermore, Bakker Barendrecht, Haluco BV and Bocchi are leading traders of fresh fruits and vegetables from al corners of the globe, with clients all over the world. Products are sold mainly to the supermarkets that tend to rule the whole business. However, vegetables and fruits are sold as well in smaller specialized shops and on week markets.

Another organisation that sells fruits in the Netherlands is Fruitmasters (Geldermalsen, the Betuwe) which is a co-operative with about 900 participating growers. Here products are still being sold according to ancient auction principles. Fruit auctions have large facilities for storing, cooling and sorting the fruit. Belgium has fruit auctions in Henegouwen, Sint-Truiden, and some special auctions for strawberries in Hoogstraten. Frugiventa.nl is a branch and service organisation for 500 members with an annual turnover of 8.1 M€ in vegetables and fruit.

3.6.2 Ornamental chains

The Netherlands is the largest producer of cut flowers and plants in the world and sells about half of the total production. This strong position is maintained by unique co-operations between producers, auctions and exporters. The ornamental chain (cut flowers and potted plants) in the Netherlands is organised according to the structure as given in Figure 8. We will describe the single players more in detail.

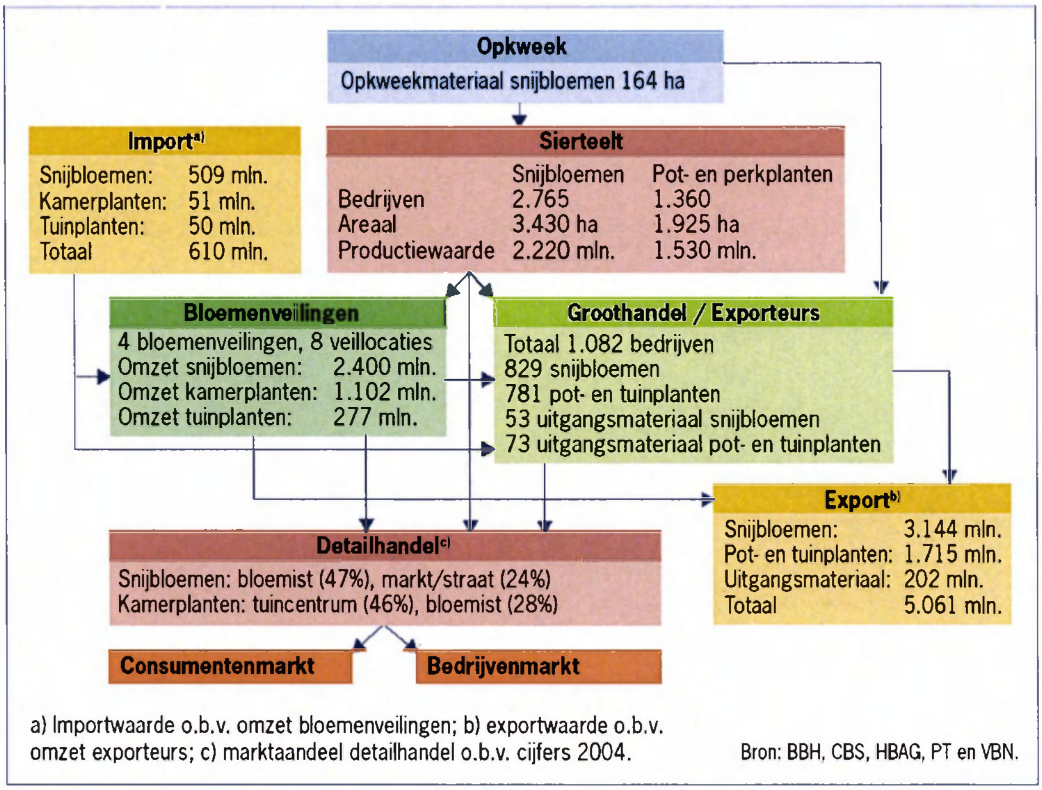


Figure 8. *A global overview of the ornamental chains (source: LEI, www.lei.dlo.nl/publicaties/PDF/2006/LEB/LEB_H08.pdf, 2005).*

Flower Auctions

In the Netherlands there are 4 flower auctions (Flora Holland, VBA, VON and BVV) situated at 8 locations. All four auctions are organised into the Dutch 'Vereniging van Bloemenveilingen' (VBN) which represents its members at all national and international political organisations.

Flora Holland, a co-operative, sells ornamental products through auction sale and contracting. It is market leader with an annual turn-over of 2 Billion Euro. It has five locations spread around Holland (Naaldwijk, Rijnsburg, Bleiswijk, Eelde and Venlo). Each location has its own character, regarding a specific area and type of products. The location Venlo is mainly targeted at selling products from open crop production and trees. Flora Holland operates 26 auction clocks, has a central negotiation organisation and has in total 3000 employees. A full description can be found on their website: www.floraholland.nl.

Bloemenveiling Aalsmeer (VBA) is a co-operative market place for growers and buyers of ornamental products in Aalsmeer (NL). It offers optimal conditions for its customers by giving a transparent pricing policy, and by offering modern logistic facilities. It works for its 3000 members and making profit is not the main goal. They play a leading role internationally and are always innovative. The total daily delivery of container plants (over 17 cm) is 2 million, for cut-flowers this is 19 million. The total daily mean average turn-over is 6.9 M€, of which 4.8 M€ via the auction clock and 2.1 M€ is sold via contract negotiation (44.000 transactions per day). This gives VBA a market share of 44.2% (2006). Daily, about 5.300 growers bring their produce to the VBA which is bought by around 1.050 traders. The most important importing countries are Kenya, Israel, and Ethiopia. Important export countries are: Germany, United Kingdom and France. With an annual turn-over of 1.75 Billion Euro, and a net profit of 5 M€ it makes VBA the second largest flower auction in the Netherlands. More information can be found on their web-site: www.vba.nl. Recently (August 2007), and because of strategic reasons, both organisations VBA and Flora Holland decided to become one organisation, which was accorded by the Dutch NMA.

Bloemenveiling Oost Nederland (VON) in Bemmel is a modern and fast growing trade centre with a wide assortment of cut flowers, pot and container plants. 600 growers from Holland and abroad daily sell their fresh products to retail, garden centres, wholesale, exporters and supermarkets. The annual turn-over (2006) is 56.9 M€. The clock was responsible for 46% of the sold products (54% via contracts). More information can be found on www.von.nl.

Bloemenveiling Vleuten BV (BVV) is a co-operative for ornamentals in the area of Utrecht. It hosts 200 growers and serves a national market for retailers, florists, mobile markets and garden centres. The annual turn-over of cut flowers is 18.5 M€ and for pot plants 4.45 M€, for in total 112.2 Million flowers and plants (2006). More information can be found on www.bvv.nl.

Wholesale, import and export organisations

The main players in the ornamental sector are the **Dutch flower group**, **Baardse** (Aalsmeer), **Blumex export BV**, **Waterdrinker**, and **Las Palmas.** A large list of in- and exporters can be found on: www.my-mps.com/asp/page.asp?sitid=689.

Logistics, Storage and Transport

Most of the transport is organized in a direct way, which means that the actual physical product and its owner (information) are separated in their way from producer to end-customer. Cut-flowers are exported world-wide via air transport. The export of potted plants and flowers to Germany and Europe is being done with trucks. Flowers and plants, from growers are brought to auctions or traders, mainly via trucks. The total count of trucks involved is about 1000 from collective transport organisations, and 500 grower owned trucks, and there a few thousands of distribution points... Individual growers give order to transport the goods, which makes the organisation of this sector rather complicated. Transport of flowers and plants is time-critical, needs cooling, and therefore has high demands on conditioning and tracking and tracing aspects. In many cases there are problems to organise transport and to deliver in time. (Source: a.o. van der Maas & Weening, 2003).

Important transport firms and other logistic players are: De Winter (Ton de Winter), Distributie VSV - Collectief Vervoer Sierteelt (Rob Aarse, policy advisor), Nederland Distributie Land (Edgar Kasteel), Exporter Metz (Gert Woeldering),VBA (Jos Blok, Head Sale and Logistics MVA), VBA (Andre Bakker, Quality Ensurance Manager), Auction Flora Holland (Perry Dekkers, Project leader BLINK), Flora Holland (Hans van der Salm, Head Market and Innovation), FlorEcom – (Henk Zwinkels), Agrifrim (Hans de Kroon, assistant logistic manager), Wentus verpakkingen (Loes van der Toolen, Sales Manager), Koninklijke Bond voor Groothandel in Bloembollen en Boomkwekerijproducten (M. Mesken, D. Guldemond), GPA-Nederland, cooled transport.

Retail

Products are being sold to end-users at supermarkets (f.i. C1000, AH and IKEA), small shops, markets, florists and gardener (centres). Cultra is the largest Cash & Carry in Europe for flowers, plants and accessories, located at the VBA.

3.7 Primary supply chains

The primary supply chain contains all direct (re-)sellers of (wireless) sensor systems, and its related technologies, materials and knowledge. In general these companies will buy near ready to use instruments from the secondary supply chain. As such, these companies are the potential reseller of the WiSensys system. Not all companies will in fact do so, because some have their own production and development facilities like f.i. Priva and Hogendoorn Automation.

The primary supply chains are split up into two parts, the ones that sell products in the production market (greenhouses and open crop production), and the ones that sell in the delivery chain. This is done because most of the suppliers have a distinguished market segment. For instance Priva does not deliver products to the Delivery Chain, and companies like Imtech and other system integrators, do not sell products in the production chain.

Apart from the technical product sellers, a number of entities are involved with supplying knowledge to the horticultural production chains. These are (private) advisors or advisor organisations (DLV, LTO Glaskracht), universities and schools of higher agricultural education (WUR, HAS), experimental stations (WUR-Horticulture, Bleiswijk; experimental station Zwaagdijk), growers collectives and Horticultural Board (Productschap Tuinbouw), and magazines (vakblad Oogst, 'Onder Glas').

3.7.1 . Suppliers for Greenhouses Engineering

In the Netherlands there is a broad range of suppliers of greenhouse engineering products for automation and growing and logistic facilities. Worldwide they are the most innovative. This is mainly due to stimulation from the primary sector, who demands new sustainable and especially economic profitable growing facilities. The closed greenhouse, new assimilation lighting, new greenhouse cover materials and mobile systems are just some examples that are invented in Holland.

Most of the companies related to greenhouse engineering are member of the AVAG organisation. AVAG, the leading trade organisation for contractors and fitters in glasshouse horticulture in the Netherlands, promotes the joint interests of affiliated members and fosters glasshouse horticulture in the Netherlands and abroad. Company names, address and website of producers of automation equipment can be found on the AVAG website (www.avag.nl). More information on greenhouse related companies in general (national and international) can be found in the catalogue of the international Hortifair. A list of participants of this fair is available on their website (www.hortifair.com). In greenhouse engineering the following products are sold.

Control and automation in greenhouses

Companies related to control and automation in greenhouses sell (and sometimes produce in house) sensors and measuring systems for T, RH, CO_2, plant temperature, ion concentration, pH, EC, global radiation, wind speed, wind direction and rain. These sensor systems are hard wire connected to the data acquisition/control computer systems. Especially for add-on products, not in connection to their standard controllers, (i.e. self supported monitoring systems, alarm circuits, gadgets for displaying measurements in the house of the grower, etc), they might have an interest in re-selling wireless measuring systems produced by external partners.

If they would decide to change completely to wireless networks, it is reasonable to expect that they are able to develop (and will realize) their own sensors and measuring equipment for their standard process controllers. They will not rely on external partners if their core-business is concerned. Furthermore, it is doubtful that they will make such a move for the North European market or the North American market. In this respect they will act very conservatively, since the risk for production losses due to equipment failure is a hot issue. These risks are covered by insurance companies, which have a large influence in these kinds of decisions and have very strict rules on the quality of the equipment that they allow to be used. However, on the recently developed and new horticultural markets by f.i. Priva and Hortimax (i.e. Turkey, Mexico, China and Indonesia), where the infrastructure is not available as in the primary markets (Europe, Korea, and North America); they might turn to wireless solutions for a number of reasons:

- Wireless connections are a cheap alternative to hard wired connections.
- Products on these new markets have to compete on a basis of economics and prize.
- Wireless connected equipments can be delivered completely turn-key from the factory at the home base.
- Installation does not rely on local technical skills in these countries.
- Decisions for these markets are not so much scrutinized by insurance companies.

Exporting equipment to e.g. China is hampered by the high risks that are involved of being copied and sold on the original home market of the product. This is especially the case, if the product has a high added value, a high novelty value, large economic prospects and high prize on the home market of the product (like climate computers and related equipments do). Turn key products and reselling third party products might prevent this from happening.

Priva, Hortimax and Hoogendoorn cover 80% of the global market in greenhouse automation. To really gain access to this market the insurance companies (Delta Lloyd, Interpolis) should be convinced of safety of wireless sensors. Some of the large companies are starting to look at wireless. Priva indicated to have a serious interest and is a large PMC.

Especially the smaller companies might be interested in applying third-party sensors and wireless equipment. Their annual turnover and profit is often too small to cover for expensive R&D on sensors and reliable (wireless) equipment, which makes them valuable product-market combinations for the wireless T en RV sensors. Potential companies are: B-E de Lier B.V, Beemster Elektrotechniek B.V., Boekestijn Elektrotechniek B.V., Bosman Topholding B.V., Brinkman Tuinbouw Techniek, Cogas Zuid B.V., Dalsem Tuinbouwprojecten B.V, Elektrotechniek L.J. van der Laan B.V., Hoogendoorn Automatisering B.V., Hortilux Schréder B.V., Hortimax B.V., Installatiebedrijf W.S. Janssen B.V., Kandelaar Elektrotechniek B.V, Lek Installatietechniek B.V., Nic. Sosef B.V., PB Techniek B.V., Priva B.V., Scherm Ned B.V., Van der Arend Beheer Westland B.V., Van der Hoeven Groep, and Wilk van der Sande B.V.

Construction, installation and automation of Energy Screens

Energy saving screens and/or shading screens are installed in almost all North European greenhouses. In South European greenhouse shading screens or shading nets are installed. Opening and closing of the screen is controlled on the basis of algorithmic constraints that contain as variables: global radiation, indoors and outdoors temperature difference and humidity difference above and below the screens. Most of these screens are controlled by a special program in the climate control computer or by means of special control boxes delivered by the screens manufacturer. Most of these manufacturers do not produce the controllers and sensors themselves, but outsource these activities to subcontractors. Since opening and closing of a screen is dependant on the temperature and humidity of air just above and below the screen, screen producers might be a good PMC for T and RH sensors. This is a small PMC, where wireless sensors are not yet applied. Companies involved are: Van der Hoeven Groep, Scherm Ned B.V.,P.L.J. Bom Holding B.V, Nic. Sosef B.V., LUDVIG SVENSSON BV, Leen Huisman B.V., Kubo Tuinbouwprojecten B.V, Kassenbouw 't Noorden B.V., Gakon B.V., Dalsem Tuinbouwprojecten B.V., Bosman Topholding B.V., B-E de Lier B.V., Ammerlaan Beheer B.V, Agro Partners Holland B.V.

Heating and CO_2 production

The heating unit, one of the main components of a glasshouse, is usually a hot water boiler. The heating unit provides the desired growing temperature for crops under production to achieve the highest quality. A good alternative to the boiler is a combined heat and power unit if extra electricity is required. Usually, a CO_2 dispenser is directly linked to the heating unit. The AVAG related companies have a great deal of experience with such cooling units as the pat and fan system (air) or hose system (floor).

In addition to their expertise in designing and installing heating and cooling units, Dutch firms possess a great deal of know-how on energy management. A variety of measures can be introduced to make the most economical use of energy; insulation, flue-gas condensers, heat storage tanks, measurement and control equipment and the use of waste heat. For example, a flue-gas condenser reduces the flue gasses produced by the boiler to 60°C.

A heat and power unit is of particular interest to firms whose electricity (lighting) demands are high. Electricity is produced by a generator operated by a gas burning device. The cooling water from the gas engine can be used to heat the glasshouse. As the demand for electricity and heat is not always the same, a hot water storage tank is a good solution. The hot cooling water can be stored in a well-insulated tank and used when required. Flue gases from a heat and power unit should first be cleaned before being used as a source of CO_2.

Hot-air heaters are falling into disuse and are only used if the crop does not require much heat. Individual gas or oil heaters are suspended throughout the greenhouse. They were originally meant as extra CO_2 dispensers. There are certain drawbacks to these heaters. Fresh air must be admitted (energy loss) to ventilate the glasshouse, while harmful gas residues present a risk.

The equipment for heating and CO_2 supply are often controlled by the process computer that is already controlling climate and other variables in the greenhouse. When the hot air heaters are used as a stand-alone heat/CO_2 supply combination they have their own measurement and control unit. In those situations they might be a good PMC for wireless measurement and control, since these units are spread over the greenhouse area. This is a small PMC, for monitoring T, RH, CO_2, NO_x, ethylene, where wireless sensors are not yet applied. Companies involved are: Ammerlaan Beheer B.V, Cogas Zuid B.V., Dalsem Tuinbouwprojecten B.V., Gakon B.V., Installatiebedrijf W.S. Janssen B.V., J. en P. Schouten Installatietechniek B.V., Kassenbouw 't Noorden B.V., Lek Installatietechniek B.V., Metazet Zwethove C.V., P.L.J. Bom Holding B.V, Schep Verwarming B.V., Technokas B.V., Van der Hoeven Groep, Van Diemen B.V., Verbakel/Bomkas B.V, W.K. Crone B.V., Wilk van der Sande B.V., and Zantingh B.V.

Water and nutrient supply

A system of diluters, dispensers, mixing tanks (or retarders) pumps and supply lines transports water and nutrients to the plants. The application of it is controlled by specialized sensors and controller programs, that are part of the overall process control computer.

Basins of collected rain water are the source of the clean water (water supply). Rain water contains the least amount of contaminating ions (Chloride and Sodium). Although of less quality, tap water is often mixed with rainwater, when there is a shortage of rainwater. The type of greenhouse, the plant nutritional system, the crop and the individual situation dictates the correct method of controlling the supply of water.

Various supply systems of plant fertilizers are available ranging from simple, risk-free but labour-intensive methods (mixing tanks for liquid fertilizers) to complex, high-risk, computer-controlled systems (water analysis in combination with a direct liquid fertilizer drip system). The choice of system often depends on the expertise of the user, the labour and cost involved and the desired quality of the supply water. When the crop is grown in gullies with rock wool as growing medium or in containers or trenches on a concrete floor or on moveable tables, the water that is not used returns from the plants as drain water. It will be re-used by filtering, by replenishing fertilizers and clean to regain the desired fertilizer concentration levels. Closed systems for water and nutrients are the result.

This is a large PMC for monitoring pH, EC, T, global radiation, RH, pX (Cl, Na, Ca, K, Mg, N, P), where already some of the companies are showing interest. Companies selling water and nutrient equipment are: Bosman Topholding B.V., Brinkman Tuinbouw Techniek, Cogas Zuid B.V., Dalsem Tuinbouwprojecten B.V., Genap B.V., Handelsonderneming Revaho B.V., Hortimax B.V., Installatiebedrijf W.S. Janssen B.V., Lek Installatietechniek B.V., Nic. Sosef B.V., PB Techniek B.V., Priva B.V., Strooper Watertechniek B.V., Van der Arend Beheer Westland B.V., and Van der Hoeven Groep.

Additional appendages and equipments

Sprinkler sets, stand-alone water and nutrient supply equipment, mist/fog generators, additional heaters etc. are additional appendages used in a greenhouse that are often produced by small companies specialised in exactly those few techniques. Often they need additional controllers and sensors to activate their equipment. This is most of the time not their expertise and they outsource the development and/or production to third-party companies. This might give a successful lead to PMC's for wireless sensors. The more so, since these products are often add-on equipments that are installed afterwards, when the grower decides that he needs these additional functionalities. Wireless equipment saves on cables and additional hardware and eases the installation of the equipment.

Phyto-monitoring and measurement

In addition to the control equipments which are available to be used in greenhouses, measuring equipment is brought on the market to support the grower with information related to the status of his crop. Due to the fact that a grower is more and more changing from a 'green-finger' specialist into a managing entrepreneur, he will not so often visit his greenhouse as before and has a need for more information on the status of his crop. Plant temperature, photosynthesis, micro climate around the plant (T, RH), sap flow, water uptake, nutrient uptake etc. are variables he wants to log and to display on the place where he is now spending most of his time: the office. The current trend is that growers want this information in real-time and as dense in time and place (in three dimensions) as possible.

Specialised firms are nowadays active to deliver these equipments. Since these sensors are often randomly dispersed over the greenhouse, wireless connection could be a good and cost saving alternative to hardwired connections. Companies already selling such devices and sensors are: Delta T (UK), Phytech (Israel), Netafim (Israel), Growlab, Eijkelkamp Agrisearch Equipment, Cutilène, Phytech, Phytools, Let's-grow.com and Grodan.

This is a large PMC for monitoring climate, micro-climate, photosynthesis, T-radiation, sap-flow, soil-substrate moisture, but currently with a low level of application yet. There is a small overlap with the PMC for water and nutrient management.

A new PMC emerging in this sector is the wireless unit for the worker entering the greenhouse. He performs tasks like: picking, pruning, planting, scouting etc. By going into the crop, he comes by every plant and is able to carry with him all kinds of sensors that can locally detect any important changes in the status op the crop. As such he can monitor outbreaks of pests and other diseases. One of the tasks they already perform is the monitoring of crop yield (Kg/m2) very locally. This data is currently inputted into a portable data logger (handheld reading device), but could as well be transmitted via wireless. As such, a central computer could as well send valuable data back to the worker to inform him about local situations based upon his local observations, after consulting a central database or performing on-line computations. This application would then be the 'Tom-Tom with radar alert' in the greenhouse.

Logistics, internal transport

In horticulture, the measure of mechanization and automation is increasing rapidly. It's very important for the output of the sector to further reduce the share of labour in the production of horticulture and floriculture. As a result we see on the northern hemisphere, especially in Europe and North-America that new logistic solutions are put into practice. In general we see three different developments:

- Mechanization of internal transport (on nurseries).
- Automation of physical handling of plants.
- Robotizing of harvesting (development of harvest robot).

In the supply industry, innovation of horticulture logistics is moving rapidly. This requires a detailed knowledge of the sector and big efforts regarding engineering and software development for the specific parts of the integral logistic system to be used in the greenhouse or the handling space. Tracking and tracing plays an important role. In potted plants production systems, individual products are being labelled (RFID) and traced around in the greenhouse. The application of wireless sensor systems becomes important due to the new mobile systems. An example of a wireless system is the wireless moisture sensing system called Sensiplant from Growlab (NL).

Seed and cuttings delivery companies

Companies that produce seeds, seedlings and cuttings deliver directly to individual customers in horticulture production. As such they can be accounted for as primary supplier. Seed companies are mostly multi-nationals, with production locations all over the world. They breed new crop species with better taste and more uniformity and potential yield for a world-wide market. Sometimes they organize the whole production chain around their products so to get their products in the shops.

The price of seed is very high, due to the quality guarantees the companies must give on the products. Seed is transported all over the world, and bad transporting conditions might influence seed quality enormously. Here a potential application of wireless sensors may be found.

Production of seed, seedlings and cuttings is normally done in greenhouses or covered open cultures. Potential applications here resemble the ones mentioned in greenhouse engineering.

3.7.2 Suppliers for open crop production

There are very intensive research and development activities from companies and research institutes to implement agro sensors in agricultural equipment. So far only very few sensors for online measurements of crops are on the market, such as Yara-N (fertilizer), Crop-Meter (fertilizer), Harvest Lab (humidity) or Auto Scan (degree of maturity of maize). Companies like Agrocom/Claas, John Deere or Krone implement such sensors. However, the delivery chain of this sensor equipment is based on several (partly small) companies. Most of the larger companies (such as John Deere) are doing research and development on sensor technologies on their own or in cooperation with other electronic companies or/and research institutes. In the agricultural storage market the company Pessl (Austria) has started an activity with wireless sensors, this could result in a competitive situation http://metos.at/pessl/.

For outdoor horticultural production the following PMC's are identified as:

- Fertlization
- Water Supply
- Weather Conditions
- Organic Farming
- Driver assistance
- Economy & Environment
- Safety at Work
- Quality Assurance and Food Safety
- Special Applications

These will be described in the following paragraphs.

Fertilization

For fertilization the following sensors might be used: nitrate measuring, soil moisture, temperature, chlorophyll content, and nutrient content. The benefits for using wireless sensors here is that the fertilizer reduction results in lower costs, it might yield an increased food quality and it protects the environment. Wireless also leads to no hindering of cables, more flexibility (location) in use, and easy integration. Related companies in this sector are Hansatech (chlorophyll), Apogee (chlorophyll and oxygen), Marathon (pH and temperature), MESA (moisture and temperature), Norsk Hydro (n-sensor), and Decagon (several soil sensors).

Water Supply

Water supply and irrigation is world-wide a major topic. There is a trend in going to wireless sensor technologies. The sensor types currently used are: nutrient content, fertilizer level, water quality, soil humidity, soil quality, and EC and water tension. Here, the benefits for monitoring are: indication of useful water, qualities for agriculture, improved water economy. The benefits for application of wireless sensors are: no hindering of cables, more flexibility (location), and easy integration. Related companies that might be interested are: Stevens Water (water quality), UP-GmbH (water quality). There are already some competitors on the market like: Delta-T Devices (UK), Decagon (ECHO-probe), Crossbow (new products).

Weather Conditions

Current weather, as well its forecast, plays an important role in growing. Many farmers use weather data from regional or local weather stations, or even buy a weather station by themselves. The main benefits are: improved process-planning, for any kind of open field productions. Currently weather data can also be downloaded from the internet. The most common sensors used are temperature, humidity, air pressure, gas consistency, wind speed. When going into wireless the main benefits are no hindering cables, more flexibility (location) and easy integration. Weather stations mostly are located on a single spot on the farm, and share one wireless link to the main farmer building. This station however could for the base station for a larger number of sensors, spread over the field serving a denser network of all kind of soil and water or micro-climate related data. Weather stations are sold by many companies world-wide; a few are Columbia Weather Systems and UP-GmbH (meteorology).

Organic Farming

In organic farming, careful crop management plays an even more important role than in regular farming. The margins for management are much tighter, since a lot of chemical based supplies may not be used. The farmer therefore must rely more and more on observing his crop, and 'drive along the cutting edges'. A few of the sensors he might want are: spray indication, soil compression, and rainwater quality. The basic benefits here are: supporting quality and the assurance for organic farming (license to produce). Here as well the standard advantages for wireless can be found no hindering cables, more flexibility (location) and easy integration. Related companies for this sector in Germany: Honold (gas constitution), UP-GmbH (soil quality) ...

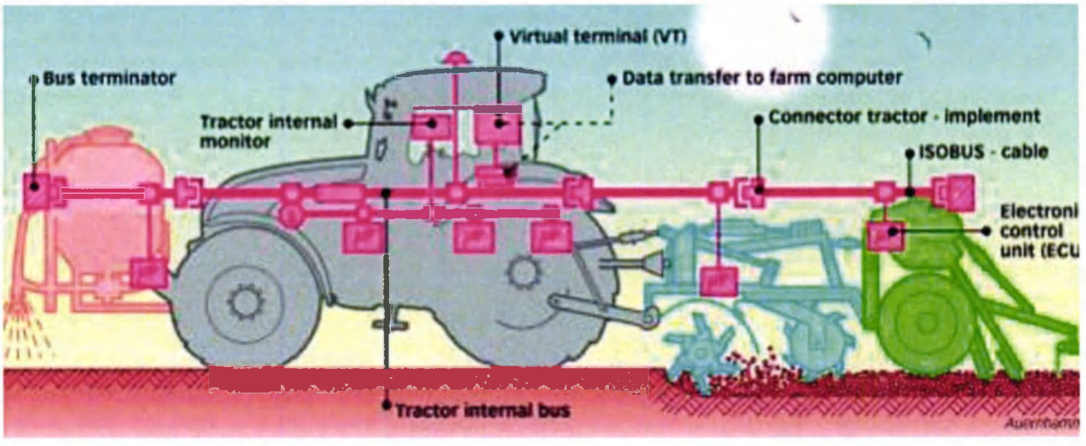


Figure 9. Tractor with sensors connected to a bus system.

Driver assistance

The trend in outdoor farming is to have larger farms and fewer workers on the field. Mechanisation and robotisation, all under the flag of 'Precision Farming' are becoming big business. At first this was observed in the very large countries like the United States and Canada, but nowadays in the larger countries in Europe these tools become very sophisticated. This means that many of the farmers equipment become 'sensorized', and standards for connecting sensors to a bus-system (see Figure 9) are available now (ISOBUS, CAN bus etc.). Nevertheless, new sensors become available, which might not fit into current bus-systems, or for old equipment not yet equipped with a bus system it might be valuable to add wireless sensor systems. Sensors that could be implemented to assist the driver are for instance: camera techniques, distance sensors, tire pressure, switches, pitch sensor, fill level. (Isobus transmitter: transmission media changer). The clear benefits are: give machine operators a break and make processes safer, working faster and/or more efficient, prevent machine and operator from hazardous situations.

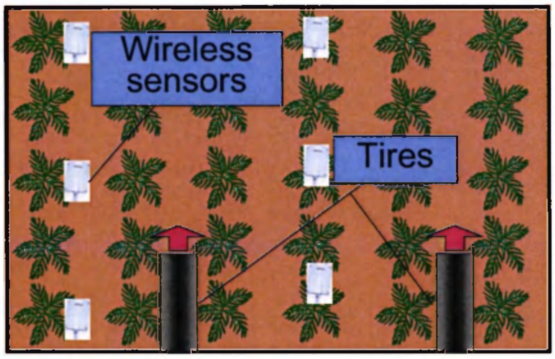


Figure 10. Wireless sensor application on tractors.

The benefits related to wireless are: no hindering cables, more flexibility (location), easy integration, weight reduction. Here the related companies are Motec (camera and pitch), Ailocom (camera), Leuze (ultra sonic), Baumer (ultra sonic), Sharp (IR-triangular), Pepper&Fuchs (switches).

Economy & Environment

Outdoor crop production is regulated by several European guidelines. Most know are the nitrate directive and the water framework directive. For a global warming perspective we all aim at producing less CO_2, and as such use as less energy as possible. Fortunately here the environmental drive can go hand in hand with the economic perspectives for farmers. Using less chemicals and energy may save a lot of money. However, farmers practise becomes less easy and that is where (wireless) sensors can be of help. Sensor types that are used are for instance temperature, fertilization, and maturity gases. The basic benefits are: decreasing energy costs and environment pollution. Benefits of wireless are: no hindering cables, more flexibility (location) and easy integration.
Related companies are: UP-GmbH (water quality), UDATA...

Safety at Work

For all types of work, not even directly dangerous work, nowadays there are regulations and restrictions for working times, tools and working environment. Sensors might help to detect possible hazardous situations and generate alarms to endangered employees. Or sensors could be used only to monitor, and to keep records, to make it possible to proof afterwards that the 'good' conditions were met. Sensor types that could be used for this segment are: noise measurement, gas indication, temperature and switches. The basic benefits are: protecting employees of possibly violation or unhealthy situations, and the advantages for wireless are: no hindering cables, more flexibility (location), easy integration, and even making sensors wearable by weight reduction. Related companies are Crowcon (gas detection) and NTTEAST (noise monitoring).

Quality Assurance and Food Safety

To get the maximum economic yield for his produce, the farmer needs to produce at a high quality level. This demand falls into two categories: a higher product quality gets paid for more by the end-user because he then has a product with a better taste, and food should be safe according to food safety regulations. Food which is not safe gets paid nothing. During crop growth all measures can be undertaken to improve the end quality of the product. After harvesting, and especially in the delivery chain, crop quality can only deteriorate are here all can be done to prevent it, or to extend the period over which the product keeps its quality. Sensor types that can be used for this are: temperature, humidity, nutrient content, vitamin content, soil humidity, light emission, radiation. Basic benefits are: guarantee desired quality and support effective process planning. Benefits of wireless are no hindering cables, more flexibility and easy integration. A few related companies are LI-COR (light radiation), Phytech (wireless PMS) and many more.

Special Applications

Besides the above mentioned applications a number of other special applications may be mentioned. These applications might try to improve harvest measurements, or might encourage research and development projects. All different kind of sensors could be used microphones, biomass, forces, pressure, temperature, . . . (many more), all having benefit from wireless connections by having no hindering cables, a more flexibility in placement (location), and the easy integration. Related companies can be found among the suppliers of agricultural machines like: John Deere (biomass), Claas Maschinenfabrik Bernard Krone GmbH and Yara.

3.7.3 Suppliers of wireless sensors in delivery chains

Horticulture delivery chains are characterized as: transport, storage, auction, wholesale, retailer, dealer and end-users of the products. In this whole chain the aims are to retain the product quality as close to harvest quality and to extend its quality lifetime ('Do not consume after ...') as far as possible. Reduced quality will lead to less income. Spilling products (due to full decay, or food safety violence) is even more costly, since it leads to total loss of income. On the other hand, as an exporter being capable of handling goods over the whole chain according to end-user demands, might lead to extra income if one is capable of proving this (monitoring). An example of this is the export of roses to England, for which high quality standards are being asked. Within these chains, the main PMC's that are identified are:

- Storage computing
- Transport climate monitoring
- Storage ambient feedback during shipping

Storage computing

Products are being stored in the delivery chain on many locations, for short or longer periods depending on the location. For daily fresh products (mostly from greenhouses) the duration in the chain (grower, auction, distribution centre, and retail) is kept as short as possible ranging from a single day up to 1 week. Here mostly cooling is used to keep the product fresh. Temperature and humidity are the most important parameters. For bulk products, harvested at a single time every year, like potatoes and fruits, special storage houses are used in which the product is being held for a much longer period up to one year. The conditions in these storage houses are stricter, and mostly the (maturity) gas concentrations in these storages are kept and controlled in very precise manner. Here even the environment might be dangerous for human beings to enter for even a short amount of time. Here as well sensors for maturity gasses are being used.

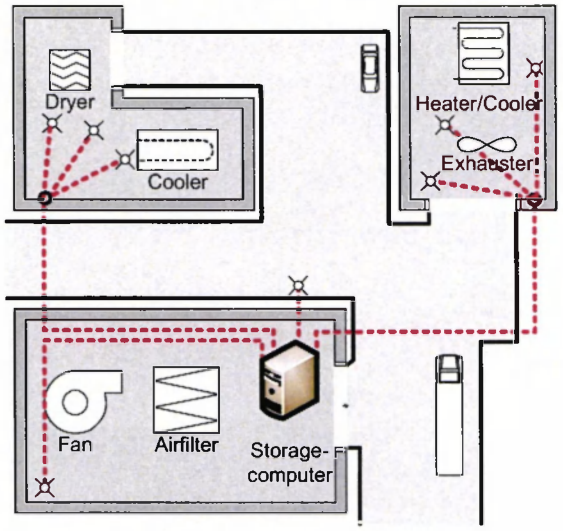


Figure 11. *General set-up of a storage center.*

The basic benefits for applying sensors are the improved quality, the assurance of quality as well as the reduction of energy use and thereby saving basic costs. The benefits of wireless are no hindering cables, more flexibility and the easy integration. Related companies that produce storage houses are LXE (warehouse management), Mooij Geforceerde Ventilatie BV, STELA Laxhuber GmbH and PRIX Dämm- & Klimatechnik.

Transport climate monitoring

Products are being stored in the delivery chain temporarily on many locations. This starts at the grower place where products are being stored in a cooling house waiting to be shipped. Further down the delivery chains and in between all stages (grower, auction, distribution centre, and retail) products are transported mostly by truck, but as well by plain (flowers), boat or train (bulk goods). Monitoring and logging of temperature and relative humidity are the most important parameters, not only during transport but especially during (un)loading while products are not under controlled climate conditions. Wireless sensors for temperature and humidity can be put inside the transporting carriers (trolleys), or shipped together inside the individual packages with products (many sensors!), and as such the sensors should be placed already in the beginning of the chain nearside the product. Readout can be done while (un)loading the trucks, benefiting from the WiSensys storage capacity. Main benefits for the transporter are the possibility of proving that the products have been kept under the right conditions. Mean disadvantages are the organisation in the whole chain and retrieval of sensors. The companies that would be customers for the products must be sought in the area of RFID suppliers.
In case not only RH and T are monitored, and the sensors are combined with RFID tags, further benefits are: reduce loss due to wastage, perishability data, improve chain efficiency, improve service (taste, ripeness), simplify process of product recall in case of crisis (including the link to the end-user), reduce 'over packaging', generate a new tool to support company processes (e.g. shorten debt periods, reduce thefts, reduce damage claims due to product, forgery), reduce data infrastructure costs, more flexible planning of company processes (from: www.datachat.nl). Further information can be found at: www.efaqts.com.

Storage ambient feedback control during shipping

In the latter PMC it was reported that logging T and RH was important to record data and so proving that the goods were transported under good conditions. But, when having available on-line data, and being able to react on that data an application could even go further. When the actual product temperature very close to the product itself can be measured (the most important data), rather than the ambient in the truck, the climate computer in the truck could be set to regulate the temperature inside the products. When temperature are to low the controller could go actively into a deep-freezing state f.i., or it could save energy when the product is cool enough. This might be true for other sensing parameters like load, weight, pressure and acceleration. In case f.i. a shipment of eggs is being done on a rather bumpy road, the driver could get feedback on the dangerous situation for his cargo and reduce his speed according to it. Other basic benefits are: preventing vibrations and shocks to loaded fruits; avoiding overload. The benefits for wireless are obvious: no hindering of cables; more flexibility (location), easy integration, weight reduction. Related companies are: Kistler (acceleration), Keller (pressure).

3.8 Secondary Supply Chain

3.8.1 Competing products

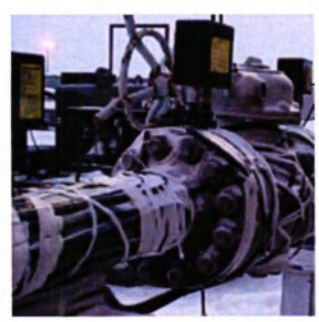
The secondary supply chain for the horticultural market contains all suppliers that indirectly supply wireless products to the production and delivery chain. They are the suppliers of the primary suppliers who are the influencers for buying. World-wide, an enormous amount of companies are currently entering the wireless market. This is mainly stimulated by new enabling technologies such as full-blown Distributed Net Technology, Wi-Fi, Bluetooth and ZIGBEE (see Bartoni *et al.*, 2007). For instance, Crossbow has launched in the second part of 2007 their new technology iMote2 for wireless sensor networks (www.xbow.com). Based upon this relatively cheap technology, third parties can develop their own hard- and software in a simple way.
Companies sell their products in a broad market. An example is the LegioNode from Ubiwave (B), which monitors Legionellosis disease in water taps. Among the many applications, a number of them are aiming at the agricultural market especially for outdoor (large range) applications. Fewer are targeted to greenhouse applications.

The WiSensys consortium belongs to the secondary supply chain. Since competitors sell their own products, no potential PMC's are identified in this part of the chain. Knowledge about potential competitors is however important by making choices for the WiSensys product.

For the horticultural market Sownet (NL), Netafim (Israel), Delta-T Devices (UK), Eijkelkamp Agrisearch Equipment (NL) and Growlab (NL) sell similar products. Most of these devices are sold for climate monitoring (weather stations) or irrigation control under outdoor situation. A few nowadays are concentrating on water monitoring (mobile systems) or stationary monitoring of air temperature and relative humidity in greenhouses.

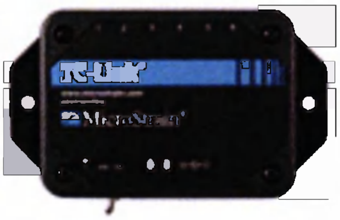
Crossbow integrates wireless networking to collect practical environmental data for T, RH, GPS, ambient light, solar radiation, barometer, precipitation, soil moisture & temperature. Applications especially for vineyards are reported.

Ember sells a variety of applications that can benefit from the low power wireless ZigBee technology.



The AquaTag (mml-Innovations) is a Dutch initiative, still under development, but reported to be a very cheap passive wireless sensor to monitor water content in potted plants. It will contain a chip that transmits water level signals by employing impedance sensoring with a resonating ring on top of the tag.

Sownet (NL) sells wireless sensor networks based upon the ZigBee protocol, developed a.o. in the Dutch LOFAR project. It can measure temperature and relative humidity and the system is also targeted for the agricultural and greenhouse markets.



MicroStrain, sells the Agile-Link Wireless Data Acquisition System, based upon the 2.4 GHz IEEE 802.15.4 standard. It claims distances to be covered ranging from 70 up to 300 m based upon the antenna configuration. A large variety of sensors can be coupled to these linearized six channel wireless nodes, e.g. J,K,R,S,T,E,B thermocouples.

Delta T Devices sells a combination of a monitoring and control system combined with a wireless link, especially for the outdoor irrigation market. The instrument is called GP1, and can host many types of sensors, such as the WET-sensor, Theta probe, temperature, relative humidity, rain gage and so on. It can control valves to be able to build a complete stand-alone irrigation computer.

Netafim (Israel) sells a similar device called IrriWise™, which is sold as a wireless crop monitoring system. It enables growers to view and analyze the real time soil moisture data continuously collected from orchards. It measures soil moisture, weather data and water usage and transmits this to a base station through a wireless data link.

Sensiplant is a system based on wireless technology that measures the soil humidity of pot plants. It consists of moisture sensors that are placed in pots fitted with radio modules, thereby enabling the sensors to communicate wirelessly with each other. Sensiplant was developed jointly by TNO Information and Communication Technology and Growlab Instruments.

Other companies

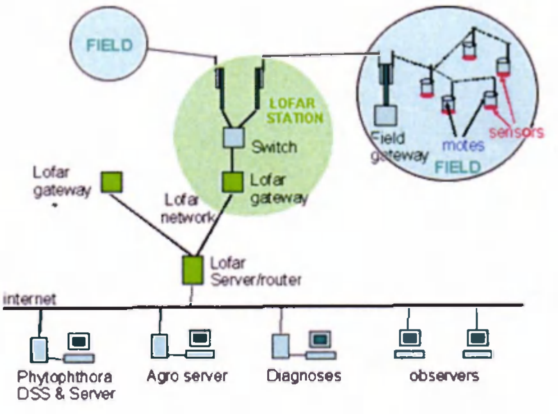
- Sensicast Smart Sensor Networks (Sensinet). RH and Temperature, RTD and other analogue inputs.
- ESI sells a wireless system (GroPoint, www.esisensors.com) that is being used in North America, especially for application in greenhouses and golf courses to measure soil moisture content. This system, however, can not be applied in Europe due to the 915 MHz is operates with.

3.8.2 Research projects

A large number of research projects on wireless sensors for agriculture have started recently. The results coming from knowledge suppliers, is expected to become available the upcoming years in a rapid pace. Examples are:

Flow-Aid (WUR, www.flow-aid.eu), for outdoor irrigation management in semi-arid countries. Wireless Sensor Experiments are undertaken container plants in Pistoia (Italy). Technology is based upon Sownet products and moisture sensors from DeltaT-Devices (SM200).

LOFAR (www.lofar.nl) is meant for monitoring and prediction of phytophthora outbreaks in potato fields. The sensor part of the LOFAR network, measures air pressure, temperature, relative humidity, illumination and soil humidity. The phytophthora project will make use of Motes, which consist of a radio transmitter and a sensor board. The radio works at a frequency of 433 MHz and can cover distances of up to 15-30 meters.



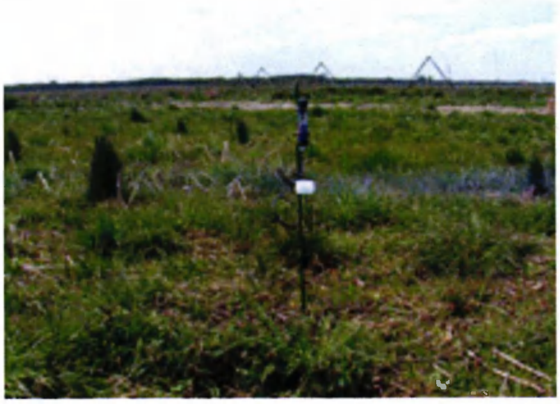


Figure 12. *Chematic overview of the LOFAR system (left) and a sensor node with T and RH sensor (right).*

LOFAR-Agro is a joint project of: ASTRON, Kverneland Mechatronics, Vertis, Opticrop, and the Technical University in Delft and from Wageningen University Farm Technology, Agrotechnology & Food (A&F) Innovations and Plant Research International. The decision support system (DSS) which helps the farmer to combat phytophthora in his crop, gathers the information from the meteorological station and the wireless sensors from the Agro Server. Based on this information maps will be made of the temperature distribution within the fields, as well as other quantities. Together with the weather forecast this information will be used by the DSS to develop a strategy on how the disease can best be prevented or controlled. It will alert the farmer of patches within his fields which are most susceptible and can be used to gauge the steps that need to be taken.

Datachat: Information capture via intelligent tags.
Datachat is based on the integration of radio frequency identification technology (RFID) with sensor technology. 'Intelligent RFID tags' capture information about product quality and logistical aspects. The registered information is then transmitted in real-time to a central information system and compared with models for product quality. This enables the product to be declared if it fulfils the stipulated quality requirements at the right moment. Datachat is a research initiative from Wageningen-UR Agrotechnology and Food Innovations (http://www.ec-pack.nl/Projects-Datachat.htm).

Figure 13. *Atachat idea (WUR - AFSG).*

Wireless Food Sensor System for soil and water, which is a Dutch research project funded by the ministry of economic affairs ('Pieken in de Delta', 2006) and performed by two universities and two companies (www.minez.nl/).

WASP: Wireless Accessible Sensor Populations (www.wasp-project.org), is a European project to test wireless sensor networks for application in animal husbandry. The Animal Sciences Group of Wageningen-UR (Lelystad) works on a demonstration of a wireless sensor network that can monitor the location of free moving individual animals, including their health status.

4 Product Market Combinations

In the previous chapter in general the target market for this survey is described, based upon a quick scan survey. Furthermore potential applications for the WiSensys system and possible buyers for it are mentioned. The next step in this research is to make a gross list of all potential PMC's that are identified. This list will be described in the first paragraph. Based upon this list of potential PMC's and based upon further analyses of the defined selection criteria, a short list of 2-3 PMC's now need to be identified for which a further market survey and technical feasibility study is to be performed. This selection will be based upon the outcome of the Quick-Scan workshop as described in the second paragraph.

4.1 Potential Product Market Combinations

In the previous paragraphs, the profiles of a number of sectors in the market segment are described, as well as a number of ideas for wireless sensor products. This is the pool from which we are looking for the most interesting product-market combination. To select a limited number, the following selection criteria will be used:

- a clear demand for wireless sensors (more sensors in a network needed);
- a near fit of the current product to the new market (less or easy adaptations);
- easy introduction into the market (competitors, acceptance of customers).

The following potential PMC's are identified in this way:

- Primary Supply Chain
  - Monitoring of shipping conditions of seeds (quality guarantee).
- Greenhouses Applications
  - (Micro-) Climate monitoring (RH, Temp.) in greenhouses (as well mushrooms),
  - Water and nutrient monitoring and control in substrates or potted plants in greenhouses (mobile production systems, mushrooms),
  - Wireless Phyto-monitoring (many sensor types, as well as water),
  - Sensor activated control of distributed equipment in greenhouses (f.i. heating systems).
- Outdoor Applications
  - Water monitoring in container for ornamental plants and trees,
  - Water monitoring in outdoor soil based crops for irrigation/fertilization management (nutrient content, fertilization level, water quality (EC), soil humidity, soil quality),
  - Fertilization in outdoor crops (nitrate, soil moisture, T, chlorophyll , nutrient content),
  - Economy & Environment (temperature, fertilization, maturity gases),
  - Weather conditions in open field production: temperature, humidity, air pressure, gas consistency, wind speed for crop protection and forecasting (potatoes, fruit trees, etc.),
  - Driver assistant for outdoor management (camera, physical sensors, spraying booms),
  - Organic farming (spray indication, soil compression, rainwater quality),
  - Wireless monitoring on mobile platforms (microphone, biomass, forces, pressure, temperature, ...).
- Delivery Chains Applications
  - Storage Computing (relative humidity, temperature, gasses),
  - Storage Ambient Feedback during shipping (pressure, acceleration, temperature),
  - Transport monitoring and logging, from grower to retail (temperature, relative humidity).
- General Applications
  - Safety at Work (noise, gasses, temperature, switches),
  - Quality Assurance (temperature, humidity, nutrient, vitamin content, soil humidity, light emission, radiation).

4.2 Selection of PMC's

As a conclusion of the workshop, the following options for the selection of the PMC's were mentioned:

- Small companies, all kinds of applications (closed horticulture)
- Climate monitoring in greenhouses, and choose one large supplier (f.i. Priva, Hoogendoorn, Hortimax)
- Sensors on machines (outdoor)
- Storage of potatoes

To make a funded selection, a SWOT analysis of the technology and the market perspective for the PMC's on the gross list is made, which is given in Table 8. This table is filled in according to the following criteria:

- **Strengths:** Does it solve a problem for the customer? Has it added value? Does it save costs?
- **Weaknesses:** Is the technology limited in some sense?
- **Opportunities:** Is there important legislation. Is there a growing market (demand)?
- **Threats:** Is there much competition? Do the customers have confidence in wireless sensors?

Table 8. SWOT analyses for the gross list of PMC's. Advantage: (+++) much; (++) reasonable; (+) little; disadvantage: (--) much; (-) reasonable; (-) little, rank is the sum of all scores.

PMC	Strengths	Weaknesses	Opportunities	Threats	Rank
Storage Computing for storage buildings in boxes or for bulk goods	T, RH. Improved quality. Assurance and energy, economy. Easy installation next to existing system (extra monitoring). (+++)	Sensor system has to be integrated into the control system of the storage building, range between PC and base station (-)	Companies in the field of storage have no know how of wireless sensors (++)	The sensors could get lost while releasing good from storage (-)	+3
Climate monitoring (RH, Temp.) in greenhouses	RH, T can be measured, wireless, relatively long distance achievable. (+++)	Influenced by direct radiation (-)	Trends in monitoring in greenhouses, energy reduction, world-wide market (+++)	Conservative market, insurance, competitors. (- -)	+3
Wireless monitoring on mobile platforms	Temperature monitoring for safety. Improve harvest measurement. (++)	Microphone, biomass, forces, pressure ...(-)	Encourage research and development projects. Huge market. High growth-rate in field of agricultural machines. (+++)	Very diverse market. (-)	+3
Mobile platform with trailer as a product	No disturbing cables that can be damaged, data logger can be placed on the platform or in the office (++)	Microphone, biomass, forces, pressure (-)	Base station on tractors for the use as a operation terminal for the trailers (++)	Companies use bus systems for reading out senor data, measurement frequency is to low (-)	+2
Storage computing for silos	Sensors with no external power supply, can be used for secondary temperature checks (++)	Reduced distance in buildings (-)	Documentation of temperature even while power blackout (+++)	PC and base station should be without external power supply (-)	+2
Sensor activated control of distributed	RH, T, Wireless. Easy installation of monitoring to existing	No wireless control facility available, coupling via local	Small companies that do not have wireless expertise. Add on	The market, and so the needed sensors and interfacing is very	+2

PMC	Strengths	Weaknesses	Opportunities	Threats	Rank
equipment in greenhouses	equipment. Local control, energy management, light. Flexible is placement. (+++)	computer. Special sensors needed: CO2, Light, radiation. Direct control (warranty?). (- -)	equipment. (++)	diverse. (-)	
Water and fertilization monitoring in outdoor soil based crops for irrigation	Wireless outdoor. Water and nutrient saving. Use of water with bad quality. Dense monitoring. Many sensors needed, due to variability. (+++)	External sensors needed for water and EC. Direct coupling for irrigation/fertigation control. (- -)	Large market world-wide, especially in areas with low water availability. Monitoring of soil water (for safety reasons) may be a large PMC (dike, flood monitoring) outside agriculture! (+++)	Many competitors. Sensor suppliers work on own solutions. Big competitors in US and Australia + NZ. (- -)	+2
Transport monitoring and logging ('chip in the crate')	WiSensys system can log 10.000 events. Quality control. Less waste. Time and logistic management. Energy. RH, T sensors available. Transporters can offer more. (+++)	Nodes must be made known to a host before using it. This might not be Handy when moving around with sensors, open standards? (-)	Quality assurance (UK flowers). (+)	Standardisation of containers and shipping vehicle systems (truck, plain, boat, train). Involves commitment of whole chain. (-)	+2
Phyto-monitoring (indoor/outdoor) **(T, RH. See climate monitoring, NO soil water)**	Wireless for indoor/outdoor. Improve crop management and planning. Quality Assurance. Wireless. (++)	New sensors needed: nutrient content, vitamin content, soil humidity, light, radiation, stem width etc. Powering of external sensors (-)	Large, growing market. (+++)	Growers not yet know what use all parameters have, many competitors that make their own equipment. (- -)	+2
Water and nutrient monitoring in substrates or potted plants (indoor/outdoor)	Wireless for indoor/outdoor. Assure water availability (reduce losses/enhance quality). (++)	Sensors for water needed. Powering of external sensors. Need for direct control of irrigation (- -).	Large market in greenhouses and potted plants (specific horticulture areas). (+++)	Some competitors are coming. (-)	+2
Measurement of the climate in an animal barn	Easy and flexible usage, reduction of cable length (++)	New sensors for measurement of CO2 and other gases needed (–)	Climate measurement inside and outside the barn with one system (++)	No need to use wireless sensors (–)	+1
Weather-monitoring (outdoor)	Wireless. RH, T available. Improved process planning (irrigation). Easy integration. Dense (local) data available. (+++)	External sensors needed for wind speed, air pressure, rain etc. (-)	Forecasts of crop diseases. (+)	Many competitors in weather station market. Online (internet) weather forecasts available. Models needed for data evaluation (forecasts). (- -)	+1
Economy & Environment	Temperature. Energy cost reduction. Reduce of environmental	Other sensors needed, f.i. specific ions or gases. EC might be an	Growing demand (in Europe) on dense monitoring systems (f.i. Water Framework	The number of parameters to be measured is large. Many sensors are not	+1

PMC	Strengths	Weaknesses	Opportunities	Threats	Rank
	pollution. Wireless and dense data network. (+++)	easy alternative. (-)	Directive, Nitrate directive). Monitoring leaching of nutrients. (++)	yet readily available. Models and reference values are still unclear. (- - -)	
Storage Ambient Feedback during shipping	Quality control. Less waste. Time and logistic management. Energy. RH, T sensors available. (+++)	Gas, pressure, acceleration sensors. Active feedback control is not mission of WiSensys (warranty). (- -)	Transport of eggs (fragile products). (+)	Standardisation of containers and shipping vehicle systems (truck, plain, boat, train). (-)	+1
Storage computing for storage in the field	Sensors with no external power supply, easy and flexible usage (+++)	Only documentation of sensor values possible, no controlling of temperature (- -)	Can be used to check the quality (+)	Losing sensors (-), work for distribution and collection (-)	0
Driver assistant for outdoor management	Faster and safer working, efficiency. Weight reduction. Easy integration. Wireless. (++)	Many other sensors needed: camera, distance, pressure, pitch, level. Connection with Isobus, Canbus. (- -)	OEM equipment. (+)	Dedicated systems needed. (-)	0
Safety at Work	T sensor. Wireless. Wearable. Protection of employees. (+++)	Gas, noise sensors. Mobile application, range unknown. (- - -)	Safety regulations. Obligatory monitoring (like radiation plate/button). (++)	For warning employees, wireless is not needed. (-) RFID-technologies are already in the market ('Kinderfinder', satconsystem) , At the Agritechnica 2007 the 'Kinderfinder' got a gold medal [1](-)	0
Organic farming	Quality, Flexible, easy integration, wireless. (+)	Sensors needed: spray indication, soil compression, rain water quality (-)	Assurance for organic (green label). (+)	Small markets Diverse applications. (- -)	-1
Shipping conditions of seeds, logging during transport and storage (RH,T)	RH, T can be measured. Wireless. Logger facility (+++)	There is no logging capability in the device unless there is host nearby. (- - -)	Quality assurance needed. (+)	Competitors that already have loggers on the market. A large range of shipment conditions. Deliveries are small and not so often combined into larger shipped quantities. (- - -)	-2

1 Satconsystem, D-Obertheres, Hall 16, Stand C10 „Kinderfinder'. 'RFID increases safety for humans and animals'. The large number of fatal accidents and injuries on farms – especially involving children – documents the need to develop corresponding safety technology. A flexible new concept for solving this problem complex has been developed by using innovative RFID technology. Receiver aerials are installed at the front and rear of self-propelled agricultural machines. The technical realisation prevents radio shadowing effects under general agricultural conditions. The persons (or animals) are equipped with an appropriate RFID-coded radio chip that is available in the form of a wrist band, a chain, or is integrated in garments. The range can be adjusted up to a maximum of 100 m from the machine. A control box within hearing distance of the driver provides the alarm display. The device is extremely innovative for agricultural machinery and has potential in other areas such as the construction industry, or in production workshops and warehouses.

For these mentioned PMC's, and based upon the survey described in the previous chapter, possible companies that could be interested are put into a matrix. This matrix can be found in the appendix.

Based upon the presentation of the gross list of PMC's, the discussion during the workshop, and the SWOT analyses, the following PMC's were chosen to be further investigated in the technical feasibility and market survey:

- Temperature and relative humidity monitoring in greenhouses;
- Temperature measurement in storage houses (for potatoes);
- Temperature monitoring on mobile platforms.

All three PMC's have a score of '3'. For these PMC's the standard RH and T sensors of the WiSensys system can be used to monitor climate conditions either in the greenhouse, the storage house or the mobile platforms. No direct control, other than via manual intervention is needed. The system can be used next to other systems to control or monitor the process. Many advantages can be found due to wireless, the dense sensor configuration, and reasonable range in indoor situations.

Next there are a number of PMC's that have a score of '2'. These PMC's have a slightly lower scores either because external sensors are needed, or the application directly has demands for on-line control. These are:

- **Mobile platform with trailer as a product**
- **Storage computing for silos**
- **Sensor activated control of distributed equipment in greenhouses**
- **Transport monitoring and logging ('chip in the crate')**
- **Phyto-monitoring (indoor**/outdoor)
- Water and nutrient monitoring in substrates or potted plants (indoor/outdoor)
- Water and fertilization monitoring in outdoor soil based crops for irrigation

Some of these PMC's (printed in **bold**) resemble the PMC's having the higher score of '3'. Although these PMC's will not be further worked on, in the next two chapters the feasibility and market survey will refer to them were possible. Spraying booms were not explicitly mentioned in the list, but regulations here might lead to interesting PMC's.

5 Technical Feasibility

The feasibility of applying the current WiSensys system in agriculture and horticultural production chains depends largely on the technical capabilities of the system and the demands from the application. This chapter will focus on the technology implications for the three main selected product market combinations:

- Temperature and relative humidity monitoring in greenhouses;
  - Sensor activated control of distributed equipment in greenhouses
  - Phyto-monitoring (indoor)
- Temperature measurement in storage houses (for potatoes);
  - Storage computing for silos
- Temperature monitoring on mobile platforms.
  - Mobile platform with trailer as a product
  - Transport monitoring and logging ('chip in the crate')

To a lesser extend, tests will be reported on the following PMC's:

- Outdoor mobile applications
- Intra-farm agricultural equipment
- Potato fields

Based upon further investigation through literature and desktop research, and the conducted field experiments, for each PMC, the following questions will be addressed:

- What distance can be covered, and to what extend is this influenced by the crop grow and the climate in the greenhouse?
- Is the current system sufficiently reliable (wireless connection) and what expectations do the applications have on this point?
- Which sensors, or combination of sensors, should be connected to the system?
- Are these sensors available on the market, or need they still be developed[2]?
- What battery life time is requested for the application?
- The WiSensys system can not power a sensor, except from the existing passive type sensors. What demands are posed on an external battery?
- Is the existing packaging of the product sufficient, and what wishes exist for weight, colour and size?
- Based upon the existing products and protocols, are there sufficient possibilities to integrate the system with current monitoring and control systems?
- How is the system matching with existing systems?
- Are there any specifications for security and the related certification of the system?
- Are there any rules or standards on RF-protocols (international) which the system should meet currently or maybe in future?

The experience and opinion of a potential end-user of the system is off value. Therefore the WiSensys system was installed in a more permanent set-up for a longer period to let the user evaluate the system. After collecting the system, the user was asked about his experience.

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[2] New type of sensors should be identified but within the project, no new sensors were developed nor tested. Only existing sensors were used in the field tests.

5.1 The WiSensys System

The website from Wireless Value (www.wirelessvalue.nl, www.WiSensys.com) gives an overview of the system as follows:

Base Station

WS-BU-rs232 is the base station that receives the data from all WiSensys® sensors. The received data is forwarded the WiSensys® PC software through the RS232 interface. The distance between sensor and base station can be up to 1000 meters in case of free line-of-sight. WS-BU-rs232 is also used when installing and changing the WiSensys® network. The base station receives settings for the sensors from the WiSensys® PC software SensorGraph and forwards these settings to all sensors in the network. Newly added sensors receive the current network settings. This standard base station has a RS232 communication port. Wall mounting possibilities are included in the enclosure and up to 100 sensors can be connected.

Sensor (T, RH)

The sensor (WS-DLTi), in an ABS enclosure and with wall mounting possibilities and a user replaceable battery, measures temperature and transmits data to the base station. Sensing is done using an internal digital sensor. The intervals for sensing and transmission are set at installation time using the WiSensys® PC software SensorGraph.

The sensor has a unique identity and a system PIN code. Transmitted data is encrypted thereby avoiding other sensor systems or receivers to receive the data. Optionally the following values can be assigned to the sensor: Friendly Name, Minimum Trip Value and Maximum Trip Value. Trip values are used to signal an alarm condition to the base station when these values are exceeded.

The sampling rate of the sensor can be set in the range from 1 up to 200 seconds.

The sensor can locally store up to 10.000 measurements in non-volatile memory. This storage is used when a connection to the base station is not available to ensure that measurements are not lost. Whenever the sensor and base station are in range again, the data is transmitted to the base station. Depending on the sampling rate this memory will last from 3 hours up to 3 weeks.

The distance between sensor and base station can be up to 1000 meters in case of free line-of-sight. Characteristic in-building range values are between 50 and 80 meters.

The sensor is powered with one 3.6V Lithium battery. With default settings of sensing and transmission intervals, the lifetime of the battery is 3 years.

WS-DLTi has variants where an external antenna and external power supply can be used. The external antenna (WS-Acc-Ant-Ext Outdoor antenna) features an integral N-Female bulkhead type connector that mounts through the wall of an equipment enclosure. Included with the WS-Acc-Ant-Ext is a mounting kit consisting of a heavy-duty steel bracket and a pair of U-bolts, this kit allows installation on masts up to 2.0' in diameter.

The tests were limited to the use of existing sensors for temperature and relative humidity as being available in the standard WiSensys product.

The WiSensys system operates in the 868 MHz frequency band. Since it operates only during a very limited time (pulsed operation to reserve battery life), it is rather difficult to perform signal strength measurements while operating the system in a non-laboratory set-up. During experiments the criterion of reception (or non-reception) of a valid signal at the base-station was used to evaluate its operation.

Within the tests the standard WiSensys system (see figure) was used.

Figure 14. *Transmitter with a temperature and relative humidity sensor (WiSensys® sensors), a base station (WS-BU-RS232) and an outdoor antenna.*

5.2 Field test greenhouses

Apart from the accuracy of the sensors, the distance over which the signals from the sensors can be received is important. Since the application of wireless sensors in greenhouses is likely to be influenced by the crop, due to water absorption, and the large amount of metal involved in the housing itself as well as the infra-structure inside the greenhouse, we expect that the distance covered will be less than the free-line of sight distance stated in the WiSensys leaflet. However, in greenhouses, communication may also benefit from non-direct reflections of the radio waves, in case the direct line-of-sight is being blocked, due to the large amount of metal involved.

We know (from a quick walk around with the sensor) that the free line-of-site distance in the open field may reach to several hundreds of meters, and that the indoor distance may be reduced to several of meters, depending on the type of obstacles found. A general rule used at Wireless Value is: 'Each wall reduces the signal with a factor of two'. For greenhouses no data is available. Therefore experiments were undertaken to see how the WiSensys systems performs inside a greenhouse.

There are many types of greenhouses, and many ways how the infrastructure inside the greenhouses look like. In general we could divide the main parameters that could influence the WiSensys system performance into:

- Height of the greenhouse divided into low (2 – 3 m) and tall (3 – 5 m).

- Size (floor surface area), ranging from 0.1 ha up to 20 ha.
- Type of the crop (cucumber, tomatoes, flowers etc.).
- Height of the crop, a measure for its total mass (volumetric water content).
- Infrastructure type (amount of metal inside the greenhouse, soil based or substrate based, pots ...).

To evaluate the system for application in greenhouses a number of tests have been performed:
- A climate chamber test, to evaluate the accuracy of the sensors.
- A quick indoor propagation test,
- A quick distance and crop influence tests in a tomato greenhouse,
- A large-scale and long-term experiment in a cucumber greenhouse.

5.2.1 Climate chamber test

Relative humidity and temperature have been identified as the major parameters to be measured in a greenhouse. To evaluate the technical capability of WiSensys to perform these measurements a test was performed in a climate chamber, using available WiSensys products. This experiment aims at evaluating the working of the Wisensys under the typical changing conditions (heat, light and moisture) found in a practical greenhouse. These experiments are not meant to evaluate the absolute accuracy of the sensors. For this purpose, a certificate of calibration should be obtained from an NKO-certified organisation.

For this experiment a climate chamber of approximate size of 2.5 x 2.5 m^2 was used. The RV and T control unit of the chamber used a temperature sensor and a capacitive humidity sensor. For these sensors no traceable calibration certificate was available. To monitor the climatic conditions in the chamber a self-made monitoring box was used. This box was based upon a standard available ventilated monitoring box housing, from which the existing temperature sensors were exchanged by two PT100 sensors. To calculate RH-values a standard dry-wet bulb method was used. Before the test, the temperature sensors were checked for its readings under dry conditions, and a correction was made for the observed difference. Its data was only used for comparison purposes. The box and sensors are shown in the next figure.

Figure 15. Self-made and modified standard T and RH monitoring box, opened backside with water container and two PT100 sensors.

In the experiments three WiSensys sensors were used with a different sensing element:

- A thermistor (wy1)
- A combined RH and T digital sensor (wy2)
- A PT-1000 temperature sensor (wy3).

The sensors were placed near each other, in the middle of a climate chamber. During two days (17[th] and 18[th] April 2007) data was recorded from these sensors as well as from the self-made T-RH monitoring box. During the day the set-point temperature is varied between 16 and 25 °C, and the relative humidity varies between 85 and 65%. The climate chamber was equipped with assimilation lights, simulating direct radiation from sunlight on the sensors. Half of the lights were switched on at 10.00h, and full lighting is given between 13.00 and 15.00h. All lights are shut down at 16.00h. Only sensor wy1 was exposed to direct light (day 17th), while sensors wy2 and wy3 were shielded.

Results for the first day (17[th] April) are given in Figure 16. As soon as the lights go on, it is clear that sensor 2 gives a higher reading. The dip in temperature and RH around 10:30 is being caused by a temporal removal of these two sensors from the climate chamber. As long as there is no lighting, the temperature readings of the three sensors are reasonable constant and the error is limited. For the relative humidity (wy2) it is seen that for low values (<70%) the difference can go up to 5%. However, since neither of the sensors are calibrated, this difference cannot be interpreted in way to say that one of or the other has an erroneous reading. In the early morning between 5:00 and 8:00 sensor wy2 has problems to follow the RH, and some oscillations are seen. However, this is not seen in the temperature readings.

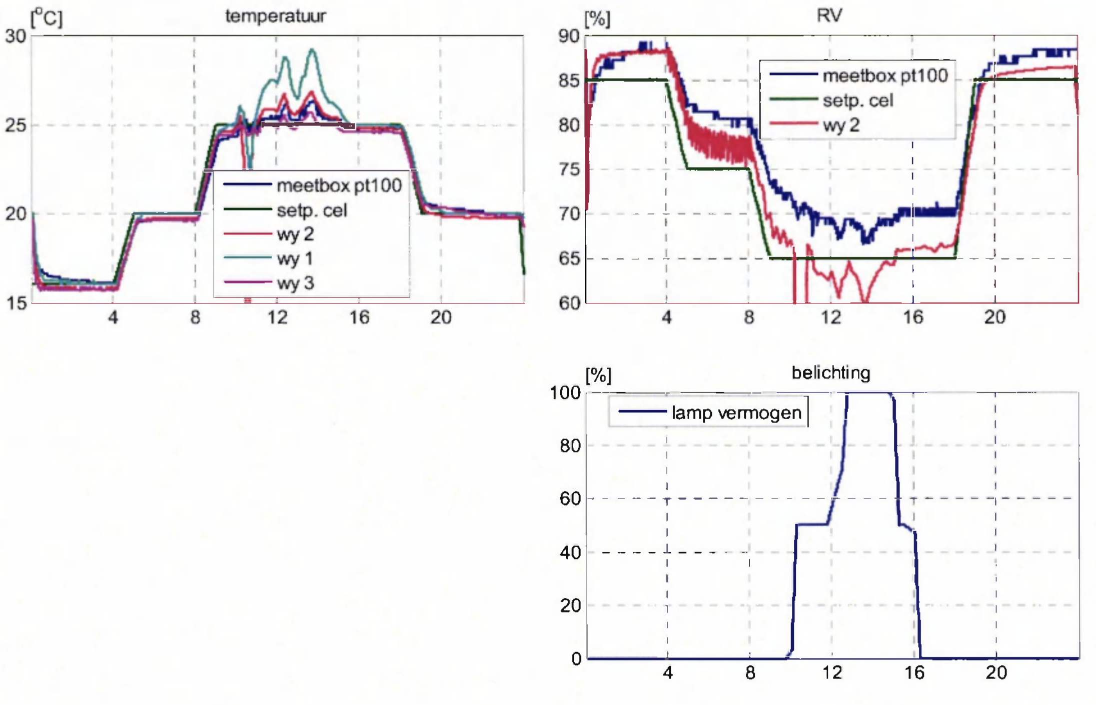


Figure 16. Daily graph for temperature and relative humidity taken from measurements from the set-point for the climate chamber, the reference box, and the three WiSensys sensors (1, 2, 3), including the status of the assimilation lights (April 17th, 2007).

In contrary to what the monitoring box is, the WiSensys RH-sensor is not ventilated. When measuring in non-moving air (which can be true for greenhouses) this might cause erroneous effects like time delays or static errors. In the climate chamber the air is moving due to a ventilator. Therefore no time-lags or errors due to this are expected. In contrary, the WiSensys RH-sensor seems to be slightly faster than the RH-monitoring box. This might be due to the fact that the RH-sensor inside the WiSensys has very little mass compared to the large PT100 sensors of the monitoring box.

In the next Figure 17 a detailed graph is shown for times between 14:00 and 21:00. When the lights are out, the readings for the temperature sensors are nearly the same. For RH the reaction times for the WiSensys and the monitoring box are similar.

Since it was seen that the sensor wy1 was influenced by the direct radiation of the lights, a simple shading screen was formed from hard covered paper and mounted above the sensor. We would expect that the influence from radiation should then be lowered. In the next figures (Figure 18 and 19) the same results as for the first day are shown for 19th April. It becomes clearly evident that there is a much lower effect from radiation on the sensor readings than before. However it is still there. From sensor wy2 and wy3 this effect is the lowest since the complete housings were placed underneath the screen, in contrary to the sensor wy1 for which only the sensing element was placed under the cover and not the largest part of the housing itself. On the second day the measurements for RH show now 'noise' during the morning.

The detailed graphs from day 1 and 2 are nearly identical apart from the temperature observed by sensor wy1. While the lights are on the difference with the temperature set-point for the non-covered situation was 3 °C compared to 1 °C for the covered situation.

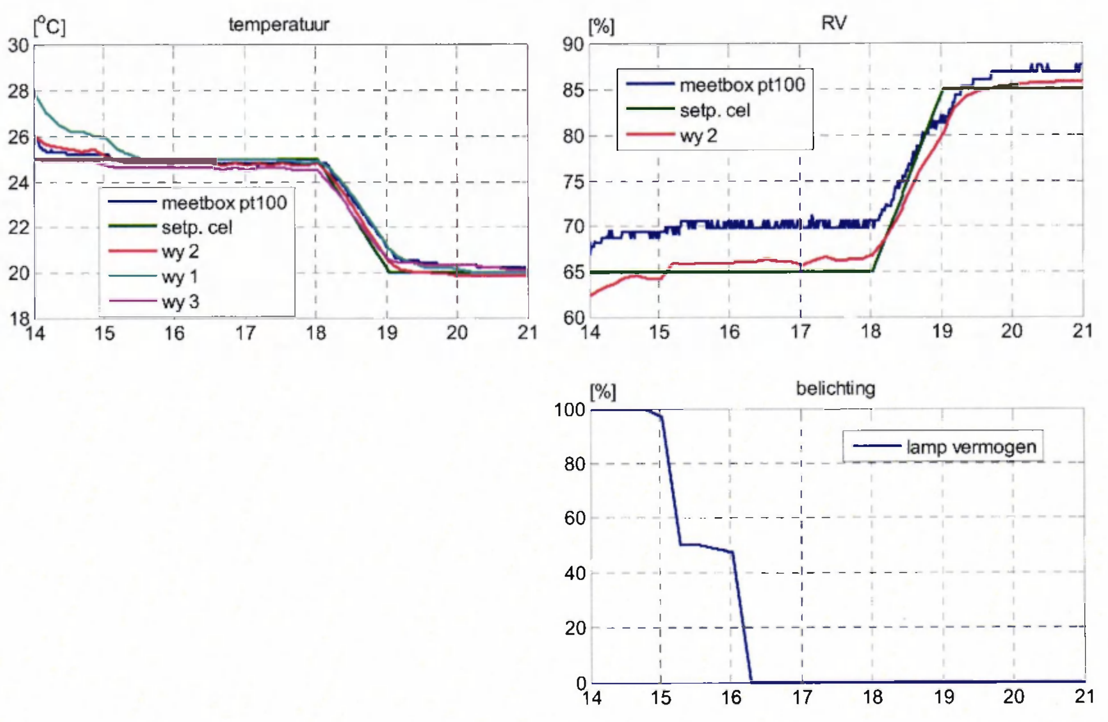


Figure 17. Detailed graph for temperature, relative humidity and assimilation lights for day 17th April, between 14:00 and 21:00.

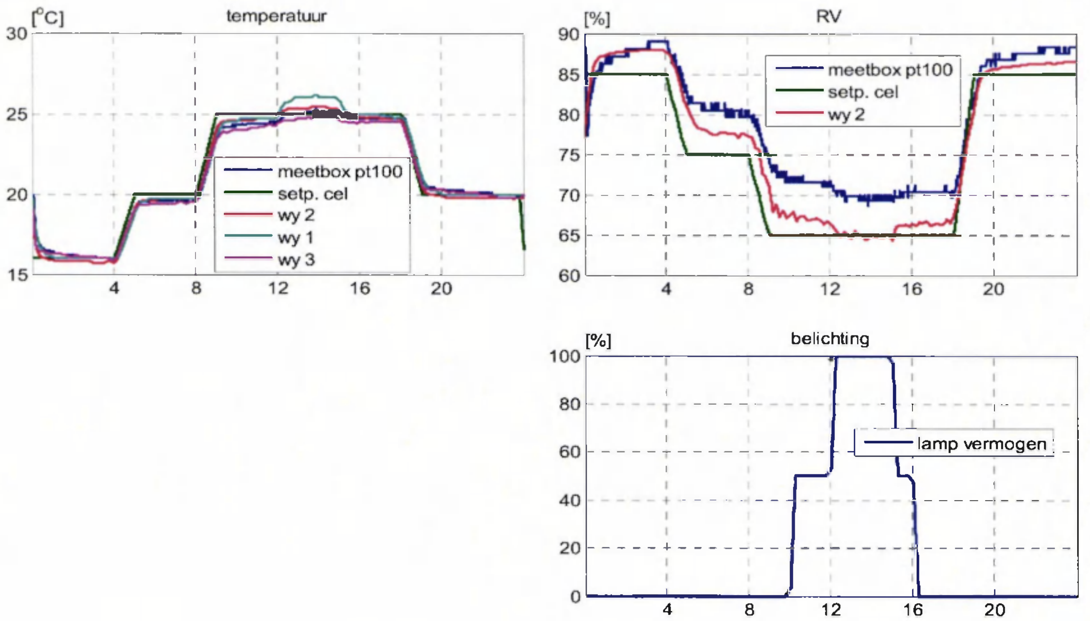


Figure 18. *Daily graphs for temperature and relative humidity taken from measurements from the set-point for the climate chamber, the reference box, and the three WiSensys sensors (1, 2, 3), including the status of the assimilation lights (April 19th, 2007).*

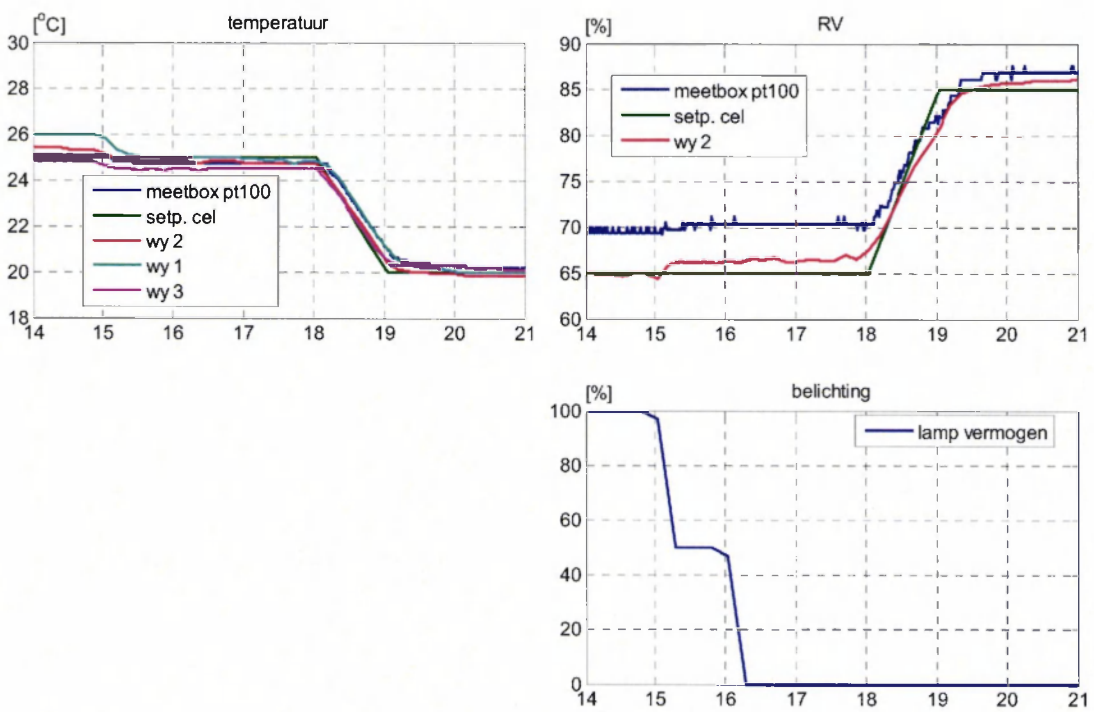


Figure 19. *Detailed graph for temperature, relative humidity and assimilation lights for day 19th April, between 14:00 and 21:00.*

Recently the Stichting Milieukeur in the Netherlands has issued a guideline for the 'Green Label Greenhouse' [SMK]. Here [SMK, 21-71] specifications are given for the accuracy of RH and T monitoring boxes for greenhouses, calibrated according to the NKO-guidelines. In the relevant range for 70 – 90% the accuracy of RH should be ±3%, and for the values below 70% it should be ±5 %. For temperature it should be ±0.2 % in the control range of 5 – 25 °C.

Although we can not say anything about the absolute values of the T and RH readings, we can see that the measured static differences between Wisensys and reference sensors are lower than the accuracy bandwidth of the SMK guideline (twice the accuracy). In Figure 19, for the adapted Wisensys sensors, these differences are not larger than 0.4 °C (2 x 0.2 °C) for the temperature sensor, and not larger than 6% (2 x 3%) for the RH sensor. Observing these differences it might well be that the Wisensys will comply with the SMK-guideline, however an NKO certificate should be obtained to be certain about it.

5.2.2 Quick radio propagation test

The purpose of this experiment was to quickly observe what the operation distance in a greenhouse might be, within the same compartment, or from one to another compartment, especially for a low density bio-mass crop.

Location: Greenhouse grower Koolhaas at Moercapelle.

Plants: Gerbera's approx. 1.5 m high

Greenhouse: trellis height 3.5 m, length 250 m,
width 70 m.

Remarks: This greenhouse was build in the late 80's with at irregular intervals placed wind shores. At the end of the greenhouse is a second compartment with gerbera's with a depth of 50 m. Between this compartment and the main compartment of 250 x 50m a glass wall is used to divide the two. An aluminium door gives access to the second compartment.

Materials

- Laptop with RS232 WiSensys base station, whip antenna and SensorGraph installed build at 26-01-2007 with Java jre.5.0_10.
- The base station is placed at the beginning and in the middle of the main corridor, at 1.5 meter height.
- Sample frequency is set to 1 s.
- One WiSensys T and RH logger is used.

Figure 20. *Gerbera crop in greenhouse.*

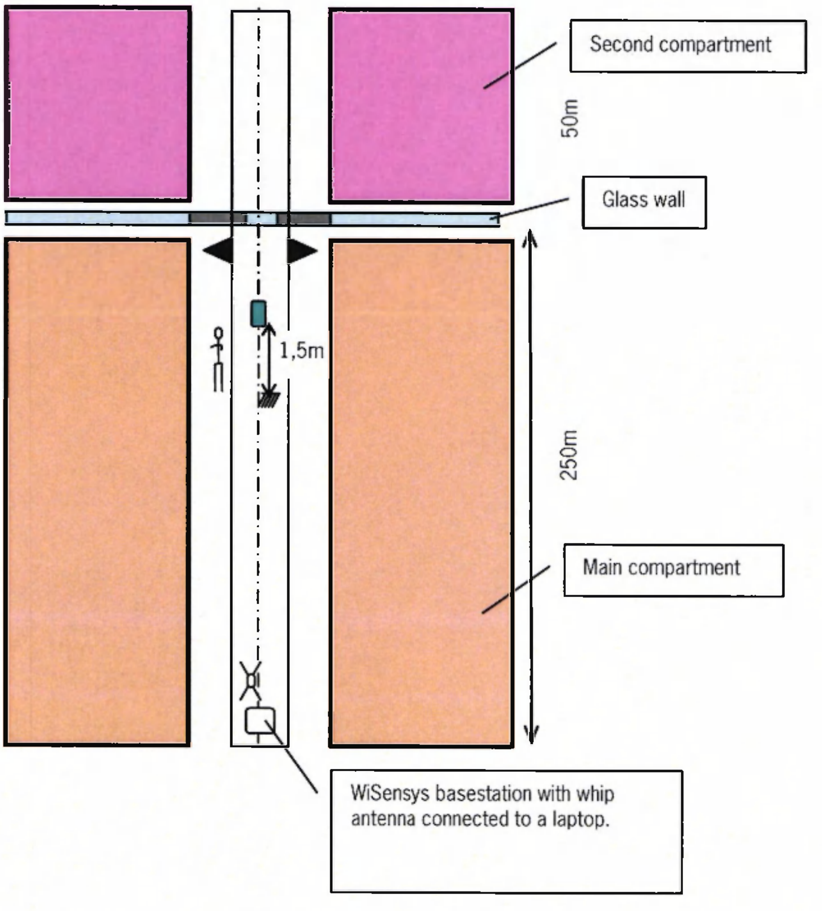


Figure 21. *Schematic of the experiment a quick radio propagation test in Gerbera.*

How the experiment was carried out

The experiment was carried as follows: one observer stayed at the laptop so check if the data from the logger kept coming at 1 s intervals. A second person held the WiSensys logger in his hand with the arm out stretched as far away from his body as possible. The second person walked away from the laptop towards the end of the greenhouse keeping the logger in the middle of the main corridor at a height of 1.5 meter.

Results

At the full length (250m) of the main corridor radio contact was maintained. When the WiSensys logger entered the second smaller compartment radio contact was lost after 10 meters (with the compartment doors closed). When the WiSensys logger was returned at the main compartment radio contact was immediately restored.

Conclusion

The WiSensys system is capable of covering distances up to 250 m in a greenhouse with a relatively low bio-mass density (Gerbera crop), under line-of-sight conditions. Infrastructures (aluminium door) significantly can block the radio signal.

5.2.3 Radio propagation in a tomato greenhouse

This experiment was performed with the purpose to observe data reliability over a period of some hours in a set-up with multiple sensors placed at several positions (distances) in a situation where the line-of-sight between transmitters and receivers was blocked by a crop with a high bio-mass density.

For this experiment a most common used Venlo greenhouse type and growing system were chosen, especially one with an infrastructure that involves a lot of metal. The experiments were performed in a tomato greenhouse in Oirschot (N.B.) owned by Corné Smulders. The greenhouse trellis height is 5 m, and it has a length of 176 m and width of 165 m. This greenhouse was built in the late 90's. The greenhouse has two compartments as shown in the figure. A glass wall is used to divide the two.

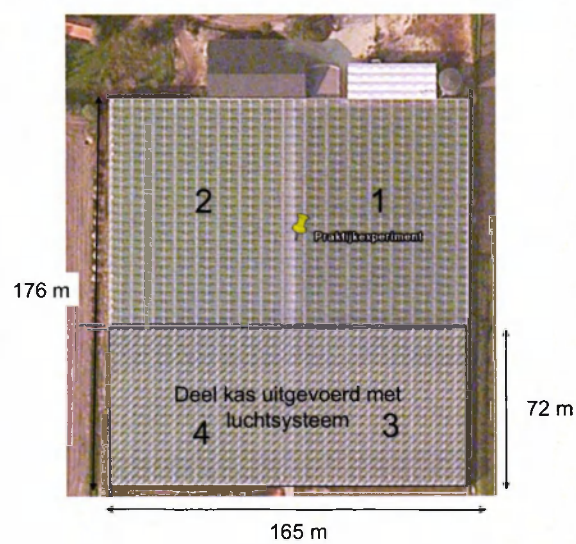


Figure 22. Layout of the greenhouse of Corné Smulders at Oirschot, the experiment was held at compartment 2 and 4.

The tomatoes are grown on mineral wool in hanging, steel type gutters. At the time of the experiment the tomato crop had a height of 4 m, and was in its production phase (tomatoes red/green).

Figure 23. Inside view of the greenhouse, tomatoes are kept in hanging gutters.

Materials

- Laptop with RS232 WiSensys base station, whip antenna and SensorGraph installed build at 26-01-2007 with Java jre.5.0_10.
- The base station is placed at the beginning and in the middle of the main corridor, at 1.5 m height as shown in the Figure below.
- Sample frequency is set at 1 s.
- 20 WiSensys T and RH loggers are used.

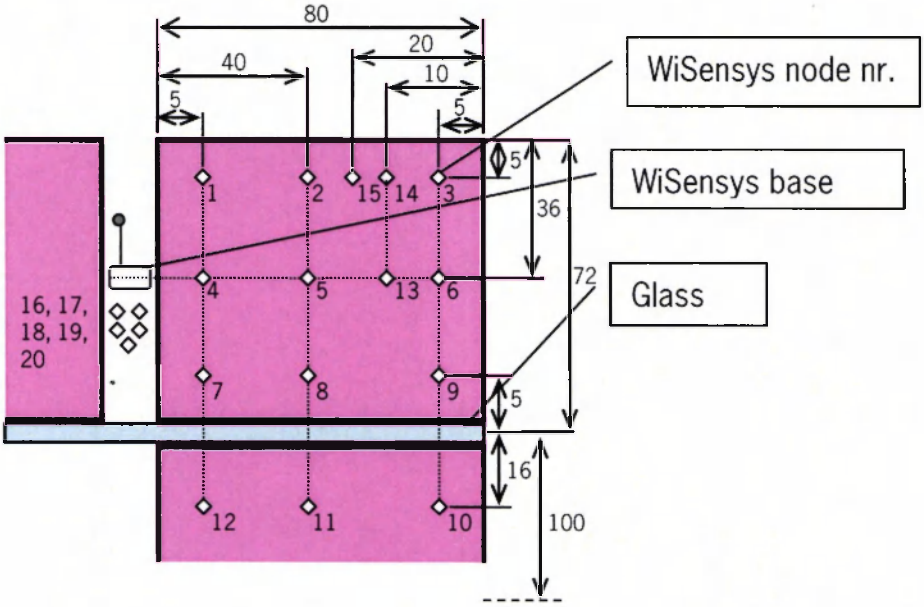


Figure 24. Experimental setup of the WiSensys base station and loggers in the greenhouse.

How the experiment was carried out

The experiment was carried as follows: the base station was placed in front of and at the middle of the main corridor of the tomato plants at 1 m height according to the figure above. WiSensys nodes 1 to 15 were placed at a height of 1.5 m in between the plants as shown in the Figure. Node numbers 16 to 20 were kept nearby the base station as a reference. At one moment the system was turned on and the temperature and humidity was logged for 3 hours. The results were transferred to Excel in which the average T and RH were calculated and the number of data packages from each node was compared to the total amount of minutes the system was switched on. The difference between both was used to calculate the data transmittance success rate (DTSR). The results are shown in the table below, and shown in the next graph.

Node ID	Distance to base station [m]	Nr. Measurements [-]	DTSR [%]	Average RH [%]	Average T [°C]
1	31	254	98.1	54.5	23.8
2	51	254	98.1	56.8	22.9
3	81	117	45.2	59.3	23.6
4	5	259	100.0	49.1	25.1
5	40	257	99.2	56	22.9
6	75	81	31.3	55.7	24.2
7	32	259	100.0	53.9	23.7
8	91	247	95.4	56.2	23.7
9	81	30	11.6	46	25.7
10	91	92	35.5	39	29.4
11	66	235	90.7	49.1	25.7
12	52	238	91.9	47.7	26.2
13	70	243	93.8	40.2	28.9
14	77	166	64.1	38.7	29.4
15	68	174	67.2	40.1	28.5
16	0	252	97.3	39	29.1
17	0	258	99.6	38.8	29.4
18	0	251	96.9	39.7	29.1
19	0	259	100.0	39.3	28.9
20	0	259	100.0	40.1	28.8

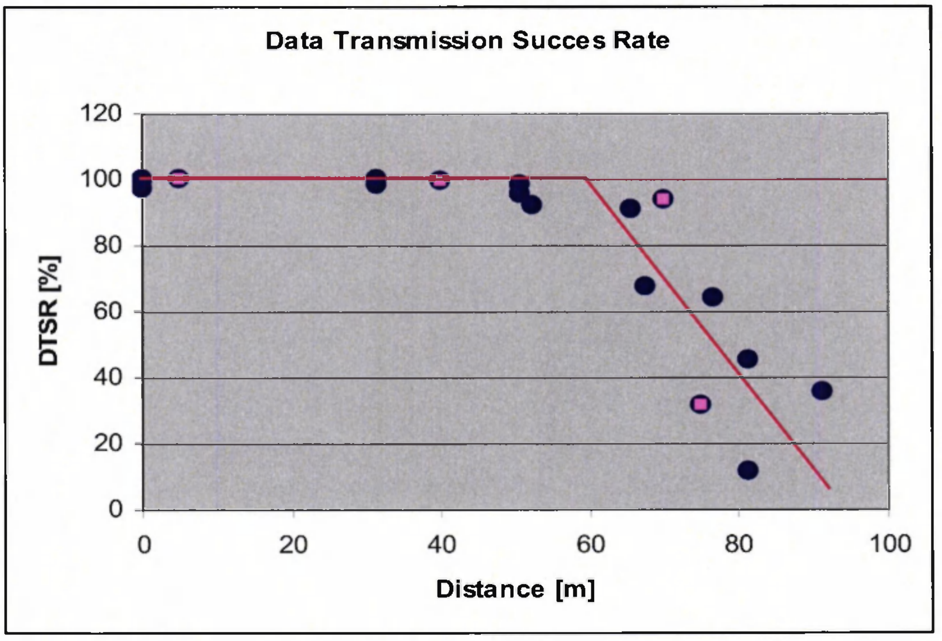


Figure 25. *The Data Transmission Success Rate plotted as a function of the distance between sensor and base station. Round dots are for sensors that are between the crop, the open dots resemble sensors that have a line-of-sight.*

Discussion and Conclusion

For distances up to 50-60 m we see that the DTSR is very close to 100%. This is even true for the sensors placed in between the crop. For higher distances the results are some what mixed. For instance, node number 6 and 10 have the same DTSR but node 10 is at 91 m distance from the base station and 'sees' a lot of plants, where node 6 has a direct line-of-sight and is placed at 75 m. The same abnormality is found when comparing node 3 and 11. Node 3 has a transmit success rate of 45% at a distance of 81 m and node 11 at a distance of 65 meter has a transmit success rate of 90% even with a glass wall in between the node and the base station. No data was recorded about this, but it was seen that the precise location and positioning of the sensors have influence on the performance, f.i. due to reflections and cancelling of the radio signals. The bad performance of the node 6 might be due to some of these effects.

It is seen that the performance of the WiSensys system in a greenhouse with a high density crop (Tomato, 4m) is influenced a lot, and its operating range is reduced to about 50-60m. It looks like that here the achievable distance is more limited by total crop biomass, rather than by the fact that there is, or is not, a direct line-of-sight.

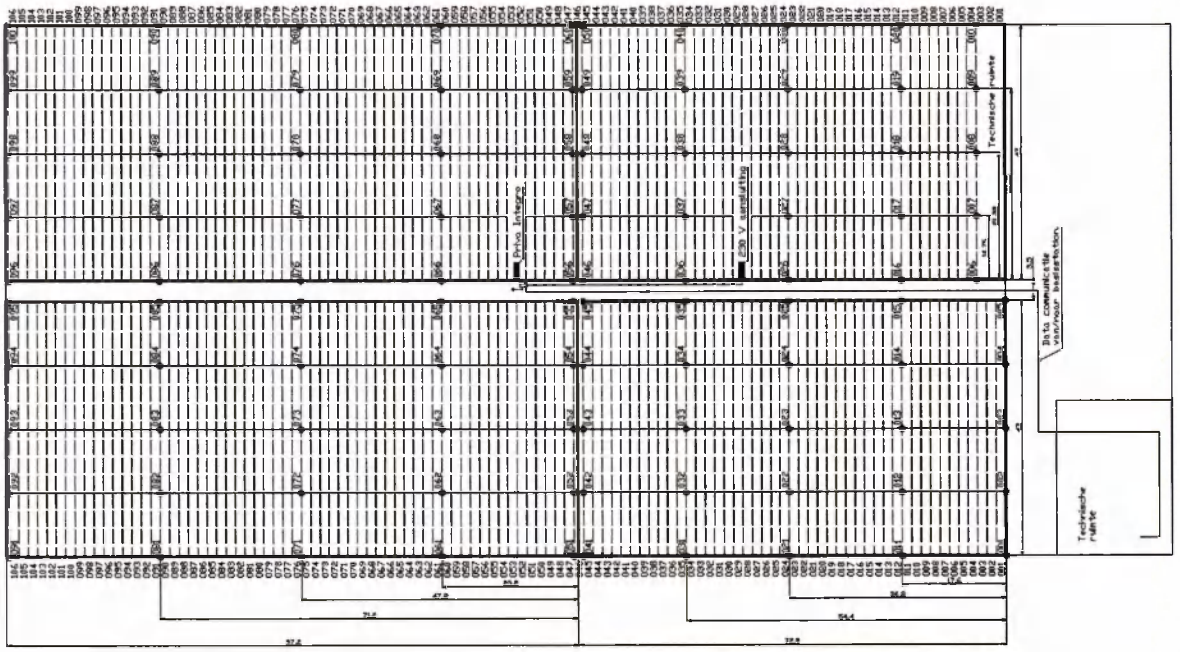
5.2.4 Cucumber greenhouse experiment

In the tomato experiment it was seen that the total biomass or density influences the performance (distance) a lot. This conclusion was based upon a single day, quick evaluation. To obtain more quantitative data about its operation (not being able to do field strength measurements), we have looked for ways to obtain this data in a simple way.

For another project, funded by the Horticultural Board ('Productschap Tuinbouw'), 100 sensors were installed in a greenhouse to monitor air temperature and relative humidity gradients in a very dense way. For this research the WiSensys concept was chosen, since currently this system seems to be the only cost-effective wireless sensor for temperature that can cover a larger distance inside the greenhouse. The main purpose of this study was to collect the T and RH data, but in parallel for the WiSensys study, we recorded the number of missing data instances for each sensor over a longer period of time. The influence of crop growth upon performance could thereby be observed. Furthermore, by having the system installed over a longer period, the local grower could be asked about his experience with the system.

In a cucumber greenhouse, located in Heerde nearby Zwolle (NL), 100 WiSensys Temperature and RH sensors were installed on August 28th, 2007. The experiment stopped on October 8th. The cucumber plants are grown in small containers placed on the floor surface in the greenhouse. The plants were already planted on August 9th, 2007 at a density of 1.4 plants/m^2. By the time the sensors were installed the crop nearly reached its maximum growing height. The greenhouse incorporates a heating system with a near the ground positioned heater distributed network and 'growing tubes' (38 sized). There is no network placed near the facades of the greenhouse, although return pipes are located near the façade. The length of the greenhouse is 170 m with in total 106 lanes to the left and right of the central pathway with a length of 42 m. The maximum height of the greenhouse is 5.43 m and the lowest point of the greenhouse roof was 4.70m.

The total area is about 1.5 ha. The greenhouse is divided into two departments of 3000 m^2 (2 and 3) and two departments of 4500 m^2 (4 and 5). Cucumbers are planted three times a year, and on august 8th the last cucumbers were planted. The climate computer used is a Priva Integro (version 725) and the grower has an ADSL line available. The WiSensys system was operated apart from the climate computer, and the local grower (Willem Doorn) might be interested to exchange information with the Klimlink software (http://www.hijdra.nl/, www.klimlink.nl).



Layout of the cucumber greenhouse and the location of the 100 WiSensys sensors.

The sensors were placed 1.5 m above the floor, at the beginning of the experiment well above the top of the cucumber plants. At the end of the experiment, the height of the crop was about 1.7 - 2 m, the sensors being between the crops. The layout of the greenhouse and the positions of the 100 sensors are given in 0. In the middle of the greenhouse an antenna is placed (base station). The antenna is mounted up-side-down on an I-profile metal bar that crossed the middle pathway 4 m above the floor. This position was chosen to have as much line-of-sight with the sensors, since the base station overlooks all cucumber plants, and even when they have reached maturity, only a few meters of crop block the pathway between sensor and base station.

The antenna is connected to the base station with the delivered cable. The base station is connected with a data cable with a PC over a length of more then 100 m. The PC was placed in the service corridor left to the entrance of the building, outside the growing departments. Next to this PC there was also another PC logging the in- and outdoor climate conditions.

It was observed that the RS232 data link was too long to have an error free link, and therefore an RS485 link (ADAM 4520, www.scs.nl) was used to replace the existing RS232 line, which was powered with 12V taken from the base station and the PC. After this, the data link performed well. The cable (a simple network, non shielded, version) was placed, with reasonable effort, inside a metal gutter.

The data from the nodes is logged on a PC with the SensorGraph software, in files in a comma separated values format (*.csv). All sensors are recorded once every minute. A file for 1 day for all 100 sensors has a size of about 7.5 Mb. The figure gives a screenshot of logged data imported into EXCEL.

Figure 26. *PC with data read-out features (RS485 link ADAM 4520 underneath the monitor).*

Figure 27. *Placement of the base station (left), placement of sensors (middle and right).*

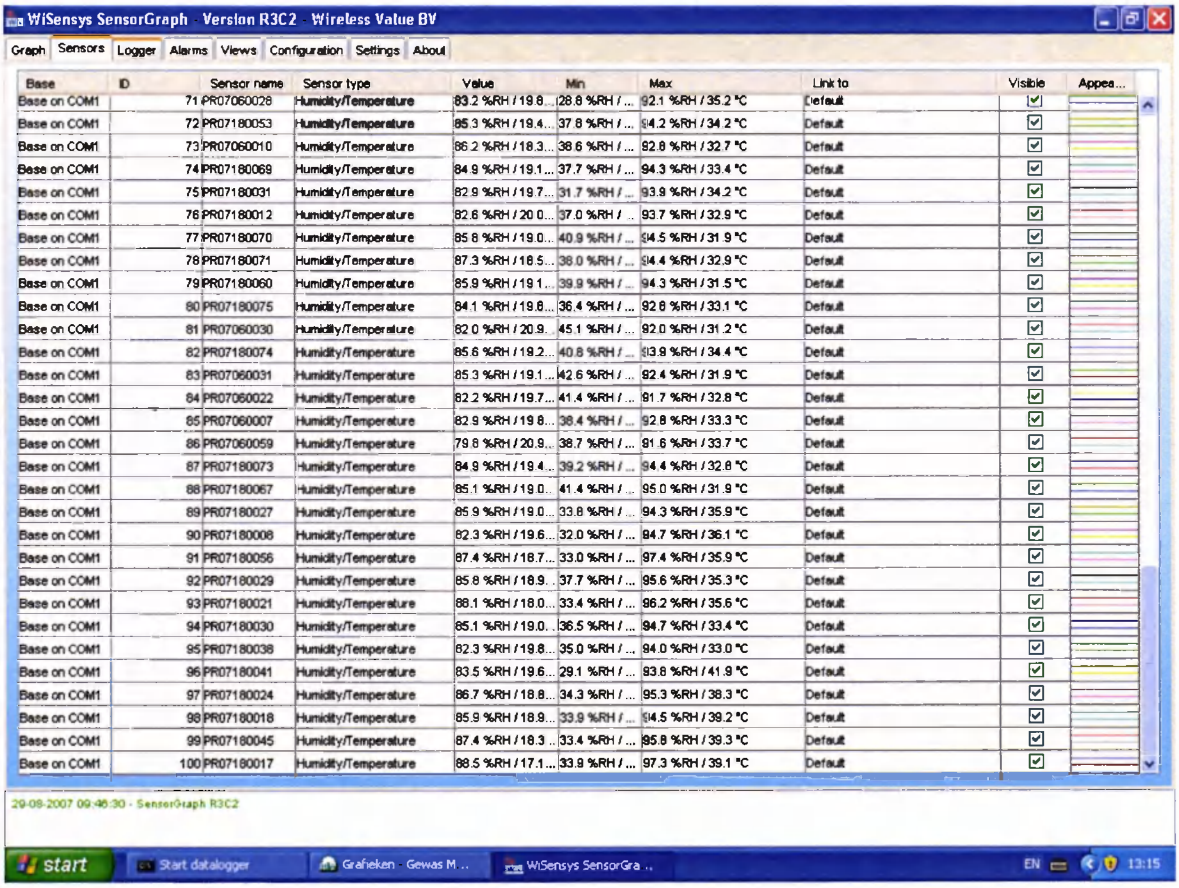


Figure 28. *Sample of the screen of the Sensorgraph (WiSensys) software.*

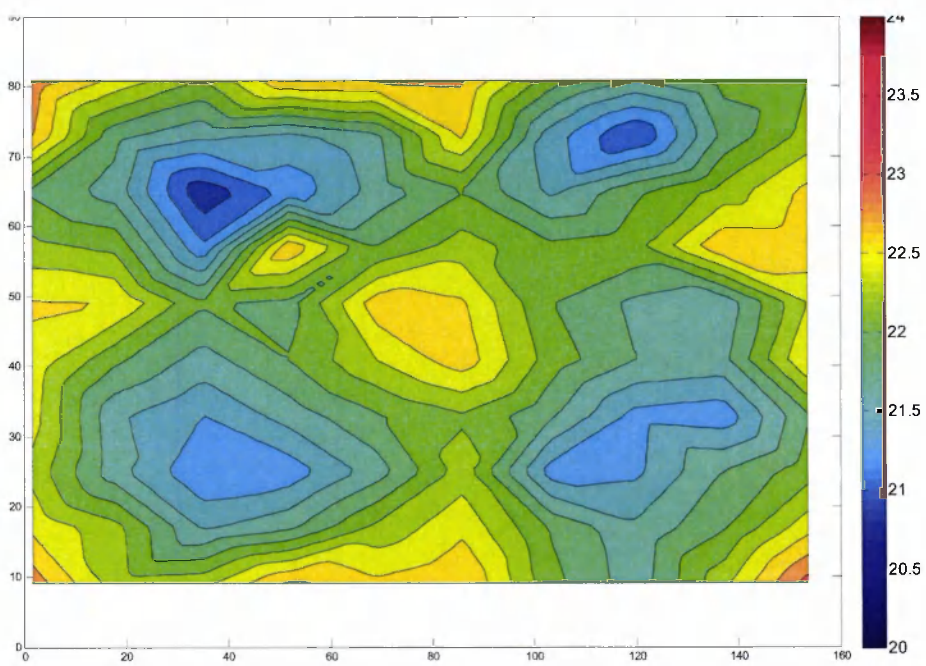


Figure 29. *2-dimensional temperature plot constructed from instantaneous readings taken with 100 WiSensys sensors, on a specific day and day-time.*

Based upon the logged data 2-dimesional plots could be obtained of the temperature in the greenhouse. Figure 28 gives an example, for a specific date and time. These plots are useful for the grower. For this experiment however, the quality of the data transmission was part of the study. Therefore, all logged data was analysed for missing data by counting the total number of data points on a daily basis for each one of the 100 sensors. For analysis, data was taken for 1 day after installation (August 29th), and a number of days thereafter (Sept 2nd; Sept 5th; Sept. 8th; Sept 11th, Oct 8th), representing day 20, 21, 24, 27, 30, 33 and 60 (the last day of the experiment). Data was taken at a rate of 1 point per minute. In nearly all days 1427-1429 data points were received per day, which is nearly the expected 1440 points (24x60) per day. It seems that 10-13 transmissions per day are structurally missed. Why this is so, we do not know. In some days however, fewer data points (f.i. 600-800) were received, which was due to a failure not related to a propagation loss, but a software/data transmission problem. During such an occasion, the maximum number of data points for a single sensor was taken to be 100% score for that day, making all data to comparable for data transmission losses. For all sensors the distance between base station and sensor was calculated with Pythagoras, only in 2 dimensions (ground floor path). Looking at this data we see that 5 sensors showed some problems with the data transmission, yielding a DTSR of lower than 90%. Two sensors even had no communication at all. The latter was probably caused by battery failures.

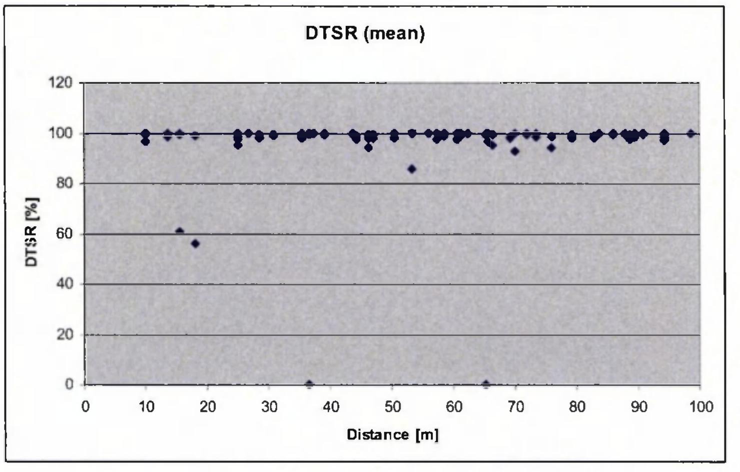


Figure 30. *Data Transmission Succes Rate for 100 sensors compared to their distance to the base station. Data is averaged per sensor over all days 20, 21, 24, 27, 30, 33 and 60.*

During the experiment we observed that for some 2 sensors the battery holding clips inside the sensor housing did not function well. We do not know what caused the other 3 sensors to have bad transmissions. Most of the sensors show a DTSR higher than 95%, which seems not to be influenced by the distance from the sensor to the base station.

Next we analysed the data to see whether there is a relation with the total biomass inside the greenhouse. To evaluate the influence of the crop biomass on the reliability of the sensor/base station connection, the crop height can be used as parameter. However, crop height was not monitored continuously, but based upon plant height at start and end, and based upon a simple grow-model and climate data, the Leaf Area Index (LAI) was obtained as a rough indication for total biomass. It is shown in the next figure.

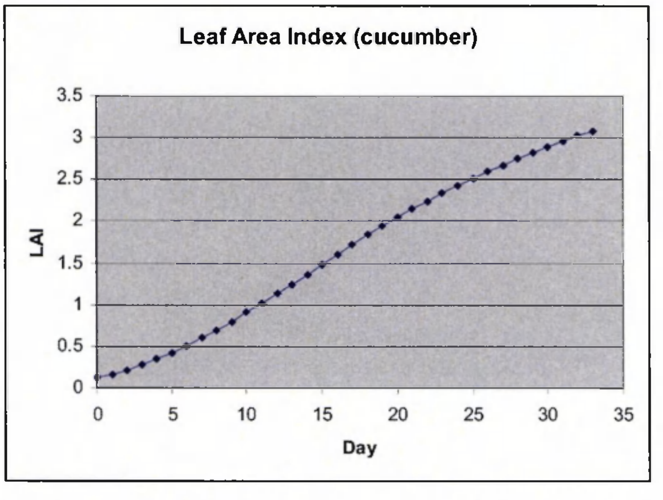


Figure 31. *Estimated Leaf Area Index of the cucumber crop per days after planting.*

The maximum height for the crop (1.7 – 2 m) was already reached after 3 weeks (21 days) after planting. At that time the sensors were installed. The LAI grew from 2 up to 3 in about two weeks. After that the crop was mature and become in a steady production state. As such we do not expect any significant changed in total bio-mass. Therefore the most interesting period was the 2 weeks after installation.

All data (DTSR) was averaged over all sensors per day, for a number of days (11) within the experimental time of 40 days. The results are plotted in the next figure.

We see that over the whole experimental period the average DTSR nearly stays at the same level around 95-96%. In this period we can not see any correlation with the total amount of biomass inside the greenhouse.

To obtain the overall performance of the system under these conditions, we decided to discard the results from a number of suspicious sensors which are sensors: 40 (85.6%); 57 (60.5%), 64 (56.0%) and 16 (0%) and 62 (0%). By doing so, the overall average DTSR is 98.7%[3].

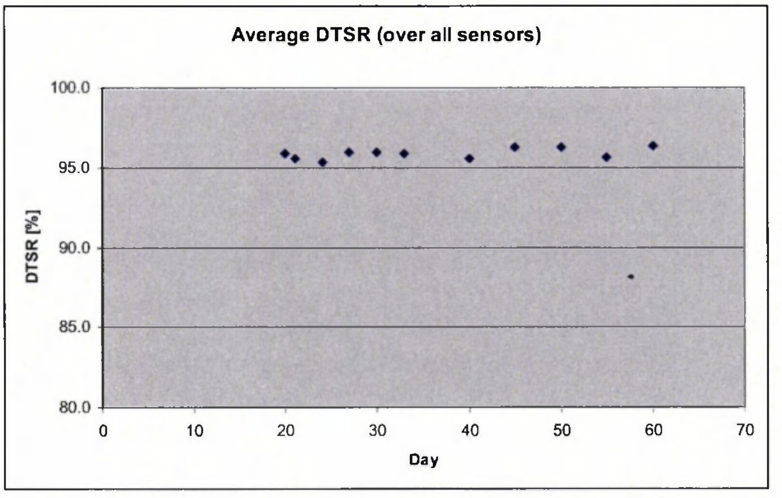


Figure 32. Average DTSR per day over all sensors.

Conclusions

The distance that can be covered in a greenhouse depends largely on the placement of sensors. In the case that sensors and base station are placed optimally (no dropouts due to reflections, and no or little blockings by the crop), then for a high density crop (cucumber) distances can be obtained reaching over 100m. During this experiment there was no negative effect observed due to the total amount of biomass inside the greenhouse.

5.2.5 Technical implications for RH and T monitoring in Greenhouses

Battery life time

For this application the standard T and RH sensors can be used. This will not require an external battery. The expected battery lifetime would preferably be one year, which would be in accordance with the time a standard crop would last in a greenhouse.

Packaging

Standard T-RH monitoring boxes in greenhouses are mounted in white painted boxes, to prevent heating due to direct radiation. It is advised to make a shading screen to prevent this direct heating. The size of the WiSensys System is o.k.

Certification

Prior to bringing the system to the market, we advise to contact an NKO certified organization (ref. WUR, E. Lovink), to let the system get a type certificate.

Integration with existing monitoring and control systems

For growers to make use of the data, it is good to have the WiSensys System be interfaced and integrated into the standard monitoring and control systems which are sold by the several companies like Priva, Hoogendoorn etc. Each

[3] It is known to Wireless Value that the sensors have an accuracy in sample time of about 1-2%, which can not be changed due to technical reasons. As a result, the sensor sends about 1% less information packets to the host.

interfacing will be different, and needs to be specially designed for that purpose, and therefore discussed with the suppliers of the climate controllers. Currently there is no alarm once a transmitter gets out of range[4].

Reliability

The experiments in the cucumber greenhouse have shown that the system works reliable enough for the requested applications. The accuracy and speed of the sensors is ok, and the failure rate (missing data) is low enough.

Sensors

For the main PMC (RH and T sensors) the system works fine. On a longer term it might be interested for suppliers to add other sensors to the system, like: CO_2, Plant Temperature, ion concentration, O_2, pH, global radiation, wind speed, wind direction and rain. This might even evolve to sensors for Phyto-monitoring: sap flow, water uptake, nutrient uptake, and moisture content. Most of these sensors are available as OEM products, but all of these sensors require special interfacing, and certainly a facility for external powering.

Range

The distance that can be covered in a greenhouse depends largely on the placement of sensors. In the case that sensors and base station are placed optimally (no dropouts due to reflections, and no or little blockings by the crop), then for a high density crop (cucumber) distances can be obtained reaching over 100m. For low density crop (lettuce, flowers etc.) longer distances (up to 250 m) can be obtained. A good position for the base station is a high position in the top of the greenhouse, over looking all plants. Sensors can be placed inside the crop, but preferably near the top level of the plants. Under no circumstances should the pathway be blocked by more than 25 m of crop to be well away from the maximum through-the-crop distance observed for tomato of 50-60 m. The transmission may work through glass windows, but metal (pillars, doors and walls) will block the signal drastically. The experiments were limited to the situations chosen for the experiments. In practise many type of greenhouses and set-ups can be found making every situation different. The best thing is to optimise sensor placement by testing its performance at installation time.

5.3 Tests at agricultural machines and storages

For the two major PMC's (storages, test setups at agricultural machines) several measurements have been performed at agricultural machines as well as in storages. Depending on the application several aspects have been considered, such as the coverage of the sensor with grain, the data transmission in the field, the range, the influence of agricultural equipment to the measurement setup and stability tests.

In terms of probability tests FHO has proofed some sensor applications with the evaluation kit of wireless value. Two tests were made with the humidity/temperature-sensor in the case of grain storage. Another test was done with the PT1000-Sensor for temperature-measurement in a potato field. The PT-1000 has been chosen instead of the ordinary temperature sensor because of its external cable which gives a longer range between measure point and radio part of the sensor.

5.3.1 Test in grain storage (trailer)

The measurement of relative humidity in grain storage might be a useful procedure for the more or less exact determining of the absolute grain humidity. The idea is to stick the wireless sensor just a few inches into the grain heap. The measured relative air humidity between the grain corns could be used as a simple indicator for the humidity of the corn itself. Easy handling of this process is strength of the wireless aspect. At first it might be a probability in storage applications because of the absence of hindering cables.

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4 Wireless Value has already found a solution for this.

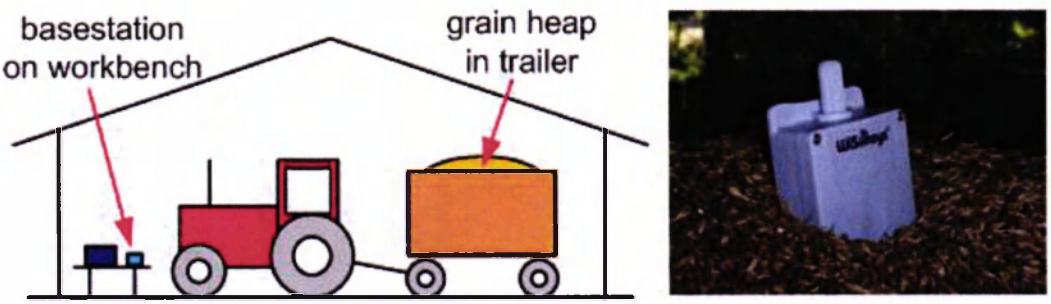

Figure 33. *Humidity/Temperature-Sensor in grain heap.*

This grain heap test was made on a grain trailer behind a tractor inside of a machine park building. The sensor was placed approximately up to 40 cm deep in the grain and the base-station, without antenna, was positioned 6m away from the trailer. The transmission signal was during the 30 minutes test procedure well present at all moment. During the procedure the sensor position in the grain heap was sequentially modified regarding different deeps in the grain heap. Furthermore in the middle and at the end of the test the sensor was completely pull out of the heap to check if the sensor will detect these abrupt changing conditions. These changing conditions were logged in a CSV-file and are shown in Figure 34.

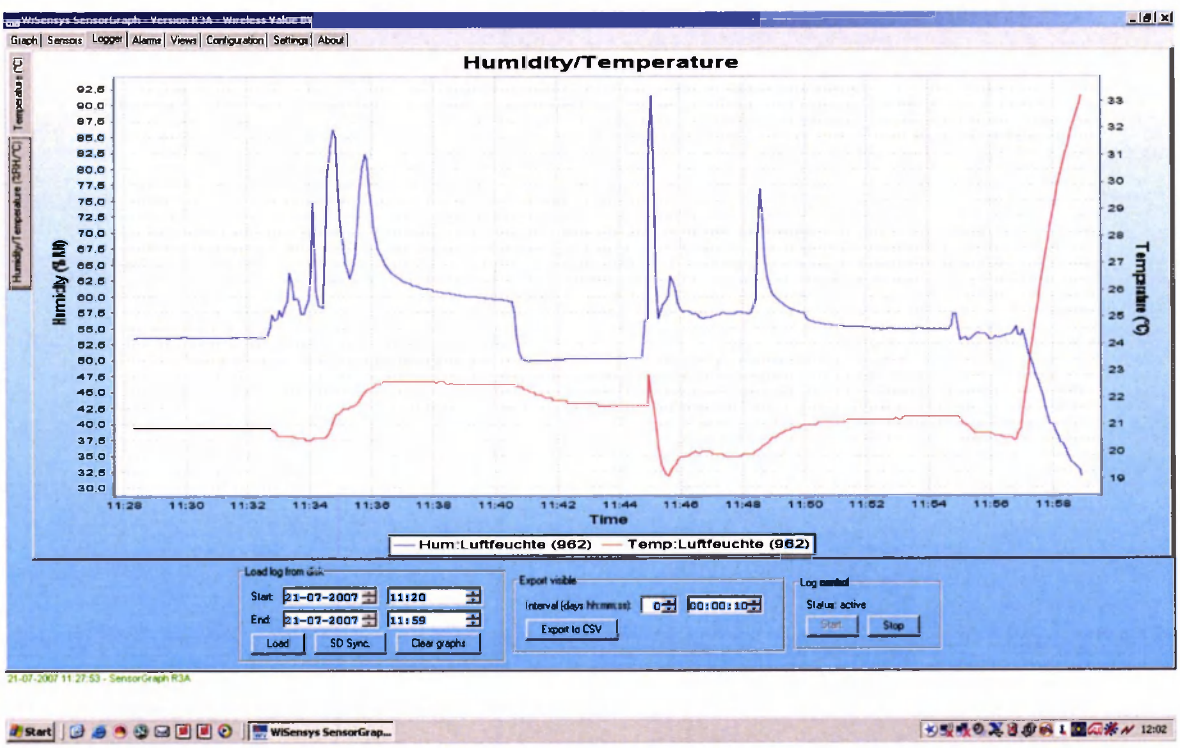

Figure 34. *Logged data during first grain heap experiment.*

5.3.2 Test in grain storage (lift truck)

For the second test the boundary conditions have been changed slightly, e.g. the positions of the sensors and the base station. The grain heap was in a bucket of an outdoor lift truck and the base station was approximately 5 m away inside of a building. The interval was shortened to 15 minutes instead of 30 minutes; the system works very well under these conditions.

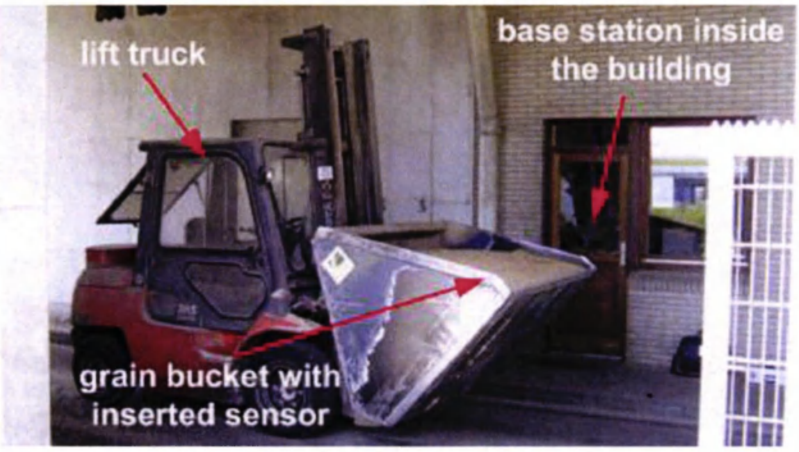

Figure 35. Experiment setup in second grain heap test.

5.3.3 Application on a harvester

In the last time the measurement of humidity has gained much more importance in agriculture due to biomass and quality topics. A direct measurement with a wireless sensor system in the grain tank might be an option; moreover applications for self-propelled maize harvesters are another one.

The standard humidity/temperature-sensor should be put in the grain tank of the machine. Previously the sensor must be installed in a kind of protection cage to ensure that the sensor can't get into the conveying screw of the harvester.

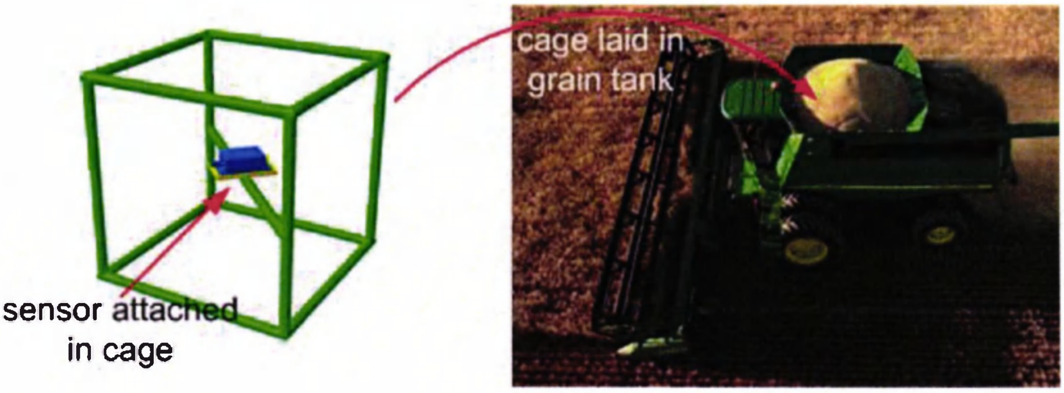

Figure 36. Additional protection cage for application in harvester.

The performed pre tests in July 2007 were done to detect if the radio signal comes throw a specific layer of the grain heap. Because of the positive results future tests in harvesters should be applied. This option has been discussed with Claas (Dr. Diekhans, +49-5247-121549 ; Diekhan@claas.com), Claas is open to perform tests one of their machines. Moreover, at the Agritechnica a meeting with Agrocom (a company from Claas in the field of Precision Farming) took place, options within Agrocom/Claas might show up in the future. A protection cage has already been realized in the laboratory.

5.3.4 Test in a potato field

This test was performed in a potato field, where absorption processes (range) are investigated. As agricultural institutions pointed out, the temperature is an important figure with respect to further processing. If the temperature has been higher than a critical temperature for some time, as for example the potatoes cannot be used for French fries. Thus the task was to measure the soil temperature in the potato field. The PT-1000 sensor was used instead of the standard humidity/temperature-sensor because of its external wired sensor needle. This short cable gives the possibility to attach the radio part a little bit higher above of the soil level. This term is important to ensure that the radio signal can come throw the leaf layers and spreads across the potato field.

Figure 37. Different sensor attachments for temperature measurement in potato field.

The base station was about 100 m apart from the sensor as shown in Figure 37. In the first part of the test procedure the sensor box was laid down just on the very above leafs of the potato plants (Figure 38, left side). In the second phase the sensor was attached at a fork approximately 30 cm above the average top level of the plants (Figure 38, right).

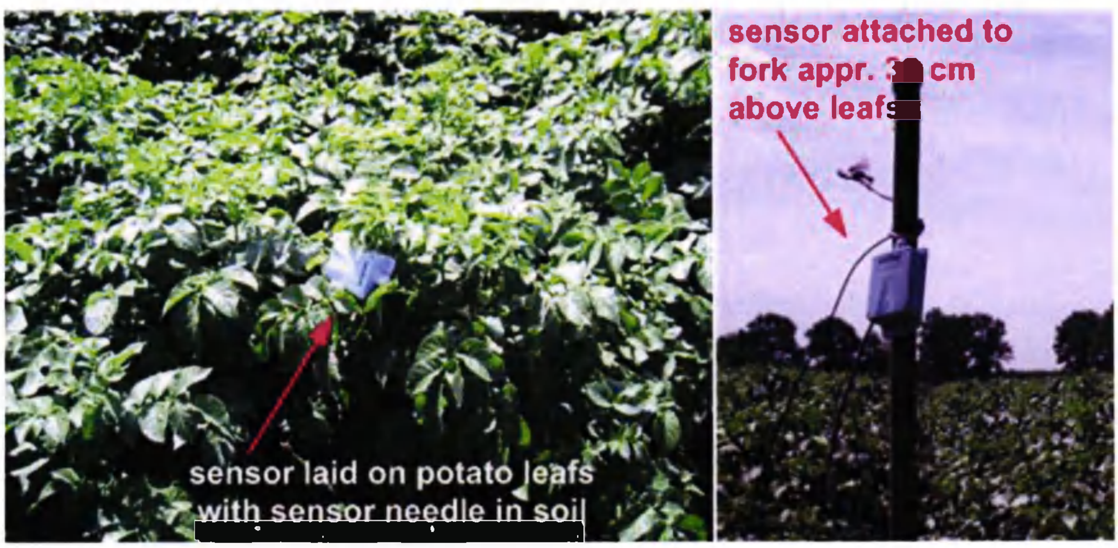

Figure 38. Base-Station positioned at low level over ground.

The first part of the experiment show that the signal couldn't received across these distance. During the second part of the test the transmission has worked well. A reason for the poor transmission behaviour in the first part is the strong absorbability of the potato leafs and the low positioning of the base-station over ground.

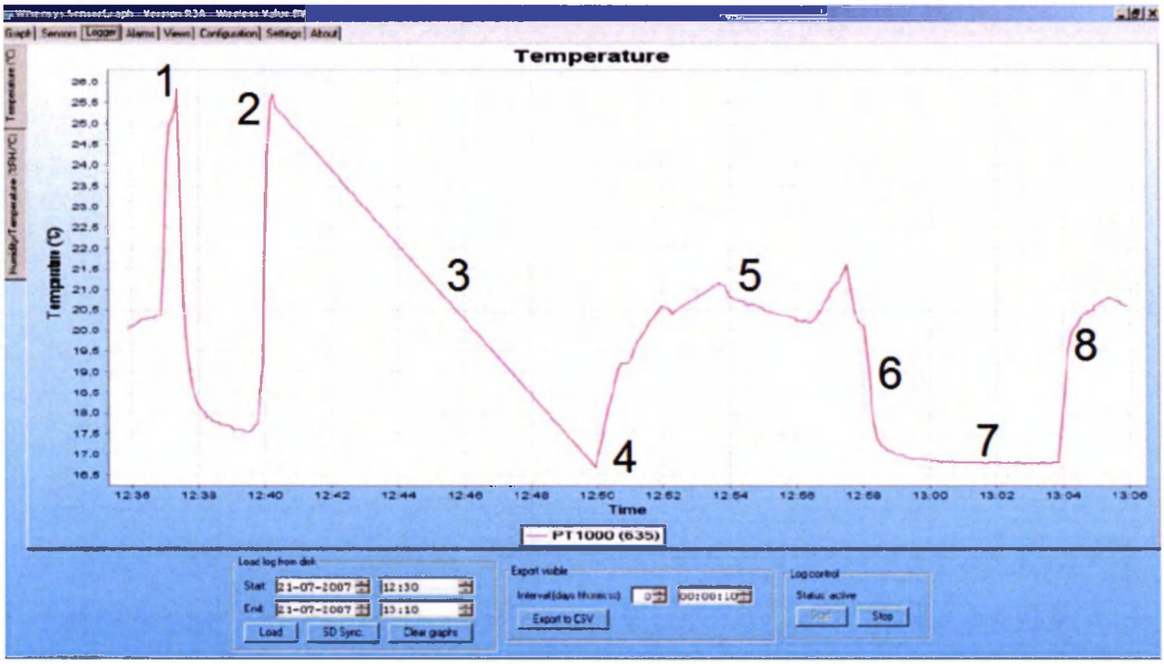

Figure 39. *Interrupted data logging in SensorGraph.*

The time interval during the poor transmission is well detectable in the diagram plot of Sensor Graph. The last data point before the break and the first data point right behind the break are connected in the diagram with a straight line (points 2 – 4).

1. Sensor is taken out of the box (higher temperature caused by touching the sensor)
2. Sensor is placed near the ground (higher temperature caused by touching the sensor)
3. No sensor signals were detected; the last measurement point and the first new measurement point are connected (linear) by the program.
4. Sensor is taken out of the ground.
5. Sensor box is fixed at a fork and placed in the field.
6. Sensor is fixed to the ground.
7. The temperature in the soil is measured by the sensor.
8. The sensor is taken out, the measurement is finished.

To summarize, the data transmission is working well when the sensor boxes are well above the plants. The system was used to monitor the temperature at which potatoes ripe in the field. They should stay under 20 °C for being a good product to be able to use them as French fries. If this could be a good PMC, one could think of burying the WiSensys system into the soil. So far, there is no experience with doing so, and the question is how deep can it be buried and how does the readout distance is influenced then?

5.3.5 Stability tests

Measurements for testing the long-term stability have been performed. For a first test the sensors have been installed in the laboratory close to a window (and a heater): One temperature sensor inside, the temperature/ humidity sensor outdoor. Measurements lasted 3 days; the base station was inside the laboratory.

As shown in Figure 40, the data transmission worked perfect over the measurement period. It can also be seen that the temperature is about 3 - 5 °C lower during the night period when the heater is automatically turned off (20.00 – 2.30).

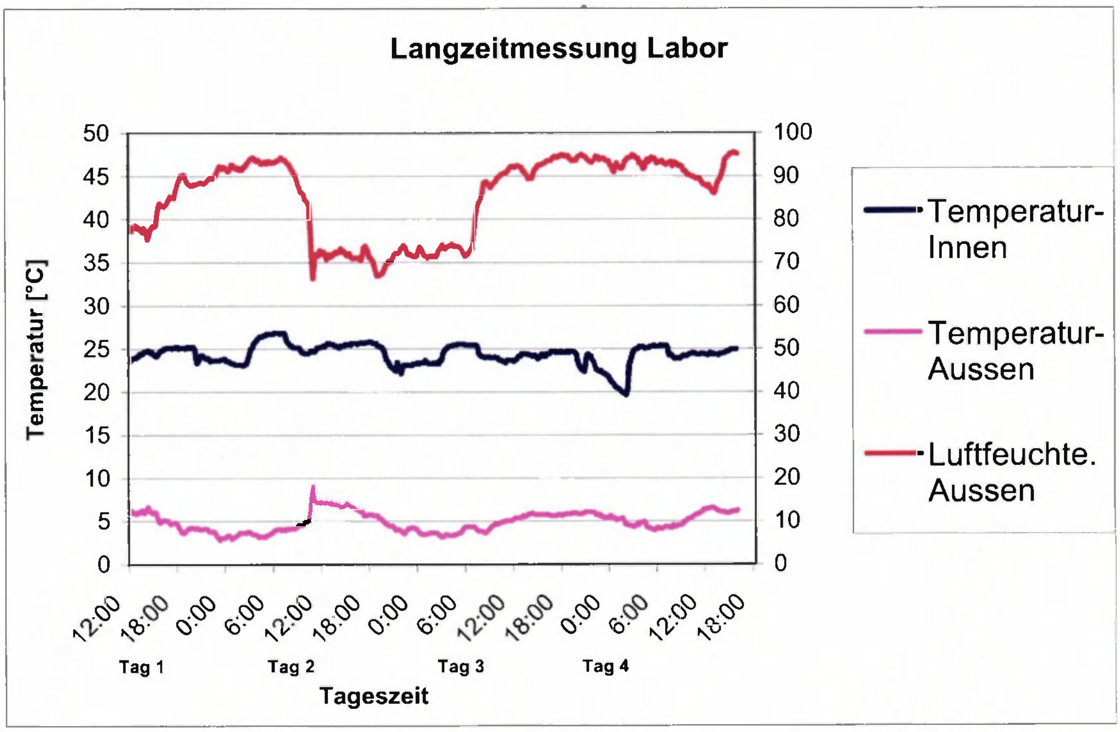

Figure 40. Long-term measurement in the laboratory.

Additional information can be given with respect to the usage of an 'old' PC (laptop, Pentium 3 processor): The CPU usage is fluctuating as can be seen in Figure 41. This is due to using Java for the live visualization with SensorGraph. This problem with an old computer does not occur in the case of data logging only.

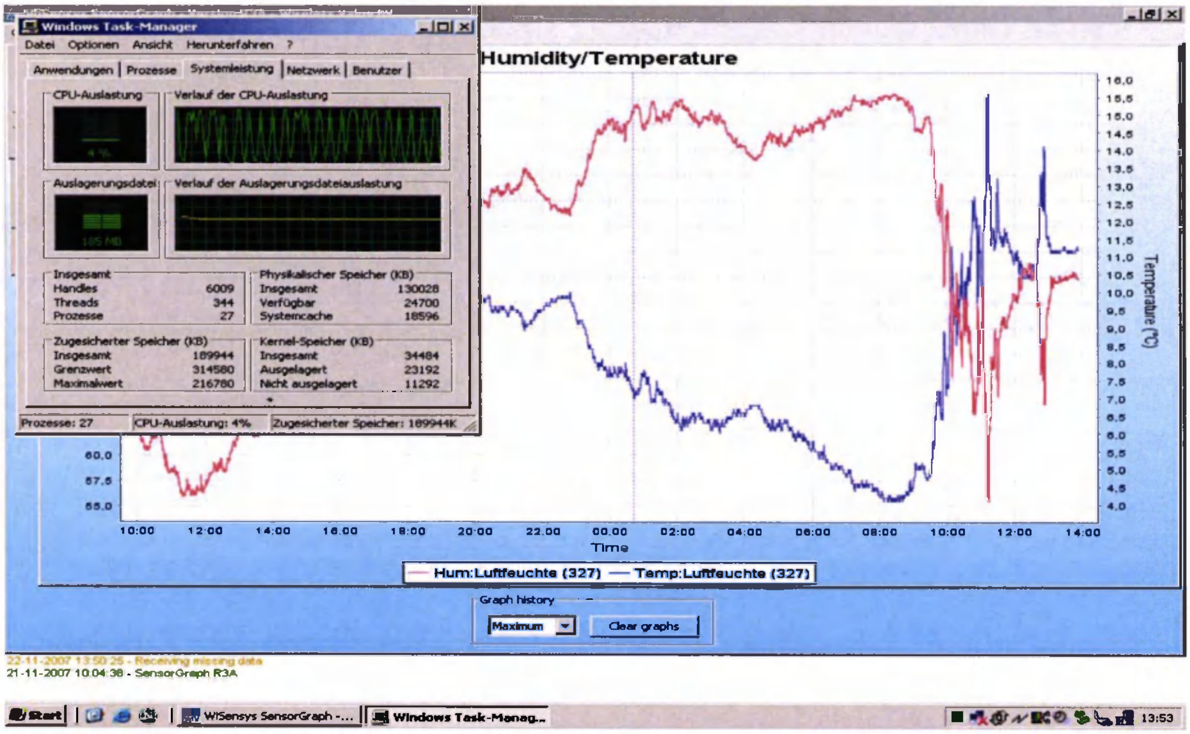

Figure 41. *Task Manager (long-term measurement).*

Another long-term measurement has been performed in a potato storage hall (Horst Brüggemann, Bramsche). There is an air conditioning system installed for stabilizing the temperature. For temperature measurements with wired sensors more than 4000 m of cables have been installed, thus, there is interest for wireless solutions. The base station is placed in the office, the temperature/humidity sensor is positioned in the air condition channel, see temperature sensor has been tested at 2 measurement points in the potato hall as shown in Figure 42.

Figure 42. *Potato storage hall (Brüggemann, Bramsche, Germany).*

Figure 43. Temperature sensors in the potato hall and the air condition channel.

The air condition is controlled by 6 wired temperature sensors, where the sensor is at the end of a 1m cylindrical tube. In Figure 43 the housing of the sensor electronics can be seen in comparison with the wireless sensor. In order to measure at the same measurement point (1 m below); a similar mechanics would have to be added to the wireless sensor component.

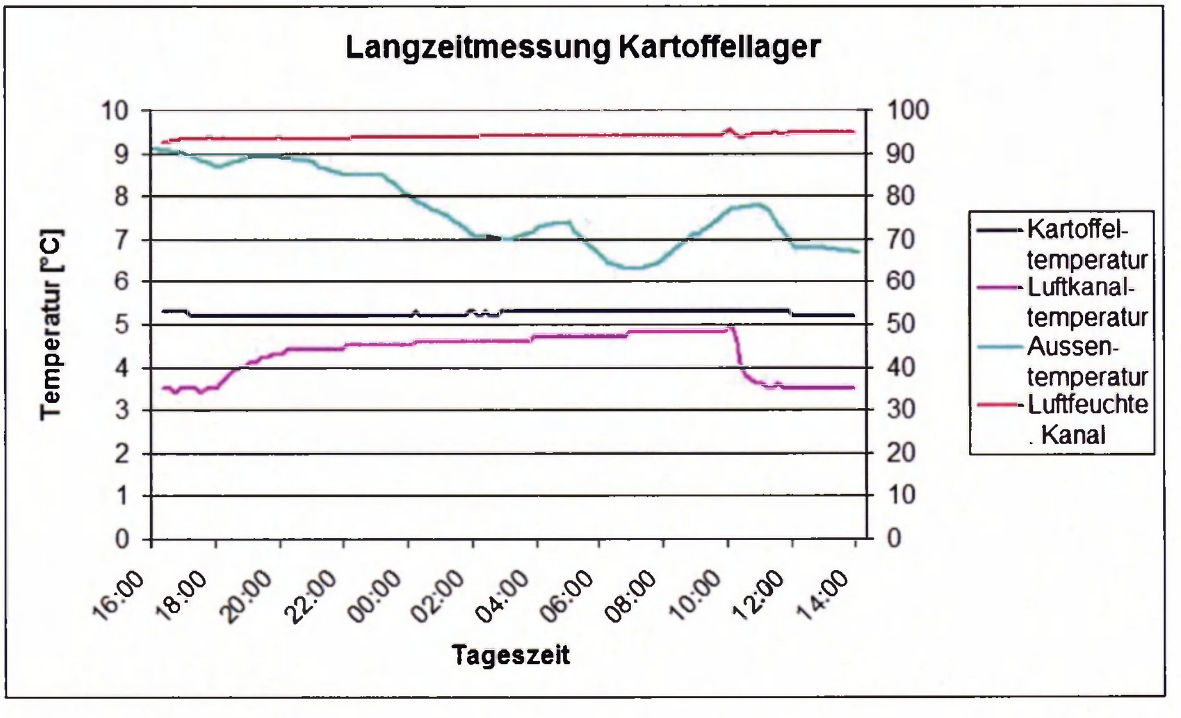

Figure 44. Measurements in the potato hall (Brüggemann). Outside temperature ('Aussentemperatur') was taken from the German Weather Service, other values were taken from Wisensys sensors.

In Figure 44 the measurement results in the potato hall are shown. It can be seen that the temperature is constant (5.2 °C). Moreover it can be seen that the temperature inside the air condition channel is lower during daytime as compared to the night, which is obvious in order to keep the temperature constant inside the hall. At the measurement point 1 inside the hall (see Figure 42) the absorption was too high, at position 2 no problems occurred for the data transmission.

To summarize, temperature can be measured in a potato hall if the position is preselected. Continuous visualization (life graph) shows problem when used with an older PC.

5.3.6 Tests with agricultural vehicles (tractor-based)

Different agricultural machines have been coupled to a tractor and measurements have bee performed with the focus on absorption processes due to the absorption in the equipment. Applications are the implementation of additional sensors or tests measurements in the development stage of such vehicles and service operations. In the first measurements a system with a tractor and two trailers have been used (see Figure 45). No problems were observed for the data transmission between the sensor (2nd trailer) and the base station (tractor) with a total distance of about 20 m.

Figure 45. Tractor with 2 trailers.

The second measurements are carried out with a tractor and a trailer for animal feeding (Figure 46). No problems occurred for the data transmission between the base station in the tractor and the sensor at the back edge of the trailer. The thickness of the steel carrier is 10 mm.

The third measurement has been performed in a closed room. The sensor is placed inside the closed seed storage of the seeding machine (Figure 47); the base station was about 30 meters apart inside the barn. The sensor was completely surrounded by metal (typically 1 mm steel). No problems with the data transmission occurred.

Figure 46. Animal Feed Mixing Trailer.

Figure 47. Seed machine.

To summarize, the results showed no technical problems with respect to the application in tractor/trailer-combinations due to absorption processes.

5.3.7 Buildings

Measurements in agricultural buildings are options for the usage of wireless sensors. As a pre-test measurements have been carried out in the laboratory of the University. The base station is placed in the room SB316 (see Figure 48) and the sensor has been moved room by room. The sensor worked fine up to six rooms away from the base station (65 m). The thickness of the walls is about 40 cm. In the red marked region problems occurred for the data transmission.

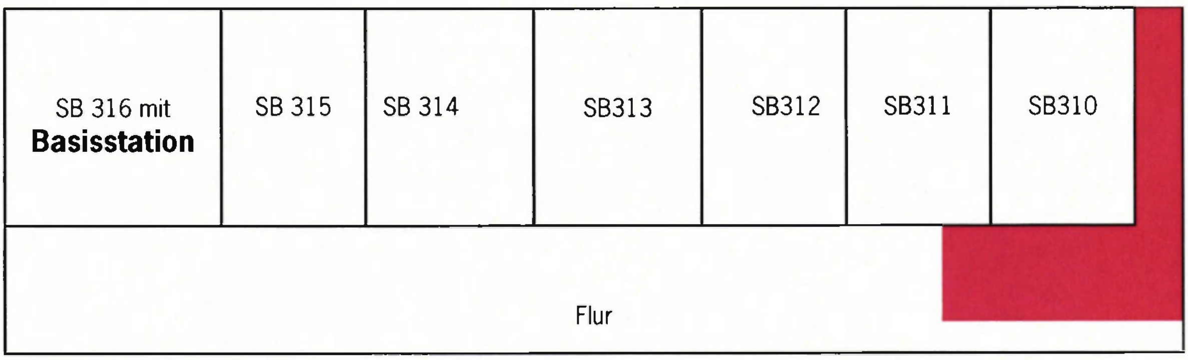

Figure 48. Structure of the rooms for the pre-test (university).

Going to agricultural buildings measurements have been carried out (farm Klever, in Halle/Germany, see Figure 49) to investigate the stability of the signal being influenced by absorption processes (walls, metal) and the operation of electric motors nearby. In the first measurement the base station was placed in the office and a sensor was placed next to the electric motor (Leistung) of the milk carousel (see Figure 50). For this measurement no problems occurred. Thus the sensors might be applied (especially for rotating systems it is interesting), in the case of more powerful motors the function, however, and has to be checked.

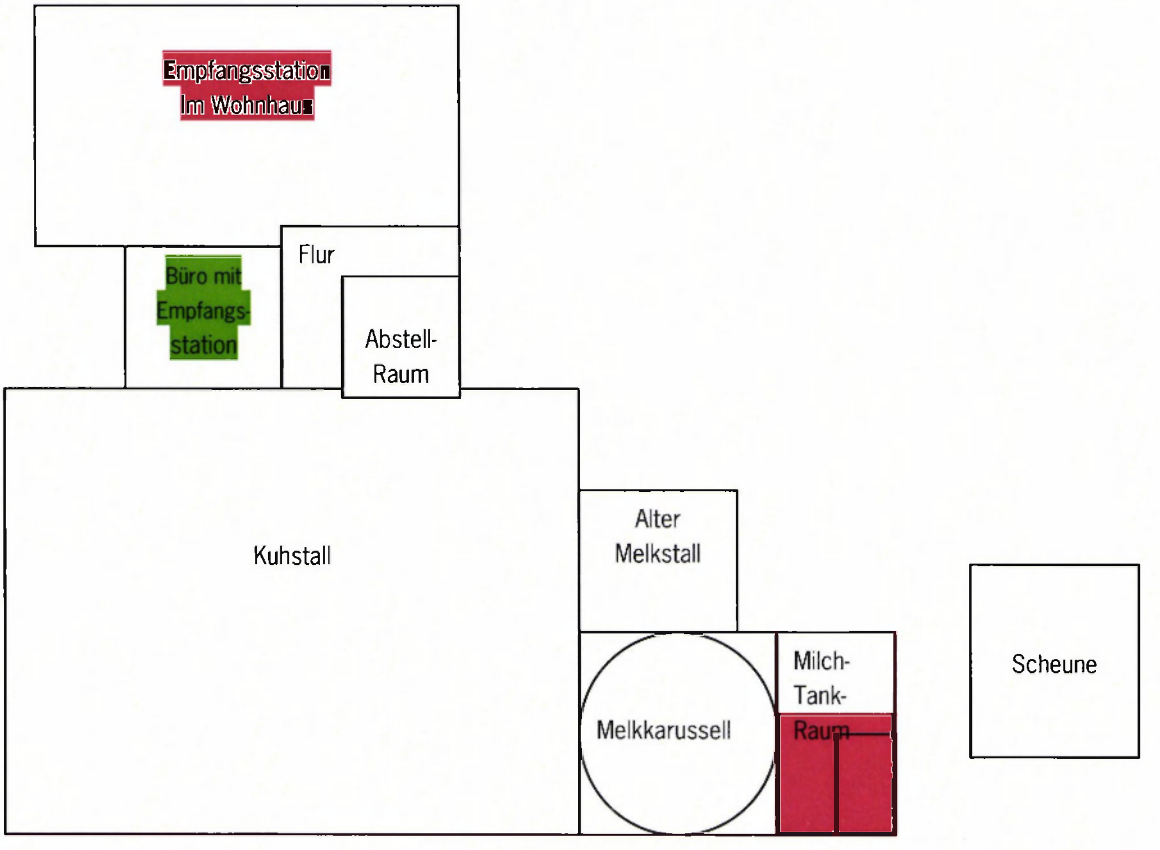

Figure 49. *Structure of the buildings (farm Klever).*

In the second measurement the sensor is placed in a tank for milk storage. The data transmission from the house ('Wohnhaus' in Figure 49) was not possible, thus the base station was placed in the office again. Problems occurred with the data transmission, the corresponding region is marked in red in Figure 49. Different absorption and reflection processes obviously influence the signal in this test thereby resulting in data transmission problems.

Figure 50. *Milk carousel.*

Figure 51. *Milk tank.*

To summarize, wireless sensor systems might be applied in agricultural buildings, as for example the control of the milk temperature is of importance (maybe as a redundant system), moreover, rotating systems and the reduction of cables are pro arguments. However, the transmission paths and absorption processes might be complex and have to be checked individually.

5.3.8 Further experiences

Sensor reset: After changing from empty batteries to new batteries a problem occurred. A new login of the sensors at the base stations was necessary with the following inputs:

- Name of the sensor
- Samples before transmission (1-10)
- Samples interval (1-200 sec)
- Maximum and minimum values for some sensors.

The loss of these data – stored on the sensor – can cause problems for the agricultural applications. Thus options for sleep modes or turn-off without loosing the above mentioned parameters (e.g. using EPROM memory) might be of advantage for seasonal agricultural applications such as storage.

Batteries: The used batteries (3,6 V, Lithium Mignon) cannot be bought in a standard shop and comparably expensive (typically 5 – 7 €). The usage of standard batteries would be of advantage for the farmer. A corresponding larger design for the housing would be no problem for the discussed applications in agriculture. Moreover the probability to interchange batteries for other applications is avoided.

Battery Lifetime: Internally the sensor is switched on/off for 10-20 ms which leads to long-battery life. With the standard sensors, and a reasonable sampling frequency, the WiSensys system can operate over 5 years (pt100, 1000, moisture RH, T, 0-20V, 4-20mA). For external sensors however this is not guaranteed, due to higher power uses. For continuous operation external power or larger batteries are needed. Depending on the application one must deal with the energy concept. Wireless Value even thinks of using mechanical energy for powering.

Sample frequency: For the measurements with the combined temperature/humidity sensor the real sample frequency differs by a factor of 2 with the sample rate given by the software.

Operation inside buildings: Buildings seem to obstruct the direct signal enormously. The antenna should be kept upright. Typical distances in buildings are 80-90 m. Rule of thumb; a single wall reduces the distance with a factor 2. In metal boxes or storage houses, the reflections are large, and finally the signal will get out.

Measurement values: During all measurements it just happened once that a strange value occurred (see Figure 52. In the case of an automatic control system, this might be problematic (example: energy consumption) in combination with low-frequency data acquisition. The time constants of the processes in correlation with the measurement frequency have to be taken into account for control purposes.

Incidental problems: Problems or limitations that appeared during the test phase:

<table>
<tr><td>PC</td><td>Base station</td><td>Sensor</td></tr>
<tr><td>Very high and fluctuating CPU usage of the software while the live view of the sensor graph is displayed</td><td colspan="2">Absorption and reflection processes obviously influence the signal thereby resulting in data transmission problems</td></tr>
<tr><td colspan="2">Distance is limited by the specifications of the RS232 connection</td><td>Loss of all settings after power failure</td></tr>
<tr><td></td><td></td><td>The loss of these data – stored on the sensor – can cause problems for the agricultural applications</td></tr>
</table>

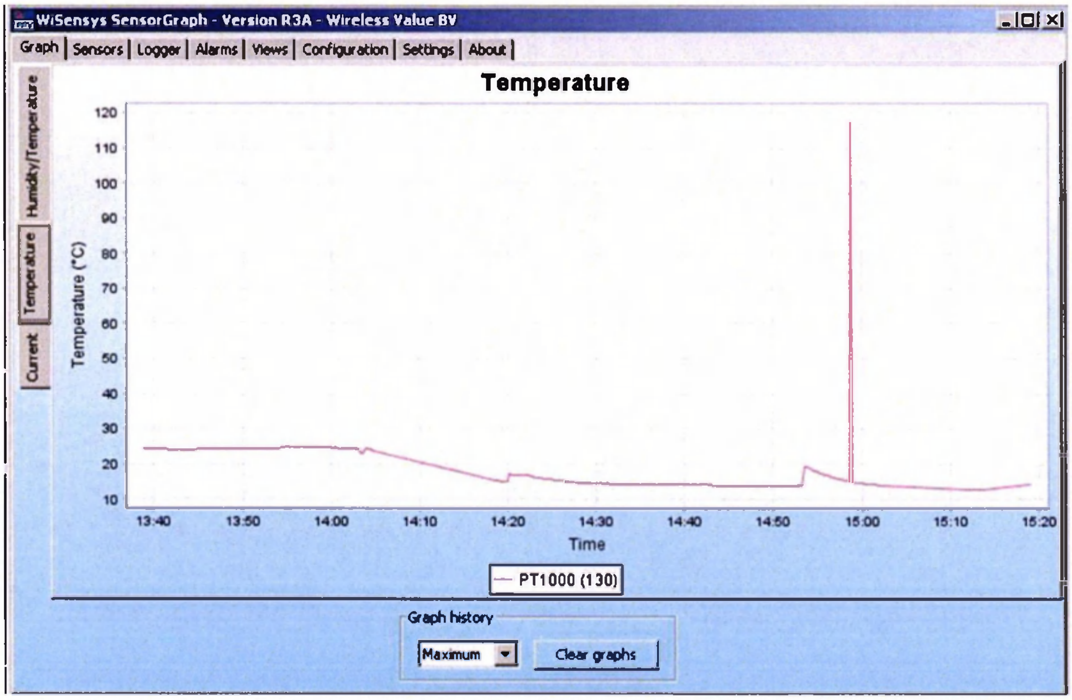

Figure 52. Measurement with a single wrong value.

5.3.9 Conclusions

In the following table characteristic information of the test measurements are given.

Table 9. Characteristic information on test measurements.

No	Sensor position	Base-station position	Distance [m]	Data transfer	Possible application
5.3.1	grain heap in trailer	in the same building of the trailer	20	+	relative air humidity
5.3.2	grain bucket of a lift truck with grain	in the same building of the lift truck	5	+	relative air humidity
5.3.4	in the potato field on the soil	around of the potato field	100	-	soil temperature
5.3.4	in the potato field 30cm top of the plants	around of the potato field	100	+	soil temperature
5.3.6	in the back of the second trailer	at the tractor	14	+	roller-bearing temperature distance measuring to the back
5.3.6	in the mixing feeder	at the tractor	5	+	roller-bearing temperature of the mixing worm
5.3.6	at the back of the mixing feeder	at the tractor	8	+	distance measuring to the back roller-bearing temperature
5.3.6	in the crop tank of a seeder	at the barn	30	+	crop class
5.3.7	on the motor of the milk carousel machine	in the office in the farmstead	60 70	+ -	motor temperature
5.3.7	at the milk tank	at the barn in the office in the farmstead	30 65 75	+ - o -	milk temperature

Storage: The test measurements and discussions showed a potential for the application of wireless sensors in storages, such as potatoes. Low-frequency measurements of temperature and humidity are important for the quality and thus are major control parameters. The range has to be checked for individual cases, however, for most typical situations the availability has been tested successfully. A sensor checking the availability of the signal would be helpful for the first installation or continuous checks.

Buildings seem to obstruct the direct signal enormously. The antenna should be kept upright. Typical distances in buildings are 80-90 m. A rule of thumb is that a single wall reduces the distance with a factor 2. In metal boxes or storage houses, the reflections are large, and eventually the signal will get out. It works from within a refrigerator.

Agricultural machines: The results for applying wireless sensors in agricultural equipment showed good results. The information needed for development or service purposes – having a look at the existing sensors – might be the temperature as shown in Figure 53.

Figure 53. Fire damage (straw baler) caused by overheating and entered stones.

However, other sensors are of much higher importance: vibration and distance measurements, DMS, angular and acceleration, IR temperature. For these cases the multi-purpose module (being available) might be used, where these sensors have to be connected. However, the data rate has to be taken into account, for several applications the concept of wireless sensors (low measurement frequencies) is in conflict with the information needed (high measurement frequency). Moreover, it could be discussed if such sensors and the module might be integrated in a new housing.

6 Market Survey

For the mentioned PMC's a market survey was conducted. This was done by short (telephone) interviews with representatives (end-users) from the specific markets in the local region. Here focus was on the boundary conditions, product price, and specifications. Competitors in the market segments were identified where possible through literature search and desktop study (internet). This survey will give answer to the question: 'What is the market potential of the WiSensys system for the PMC's', where it will focus on the following aspects:

- Possibilities for delivering services which may lead to recurring revenues.
- International possibilities.
- Priorities for additions to the system which are needed and may lead to promising business cases, and
- Partners that are needed to generate the business cases.
- Legislative incentives from customers.

6.1 General remarks about the WiSensys system

The main advantage for the WiSensys system is that it does not need any cabling, which saves a lot of costs for installation.

The WiSensys system is often used as a secondary control system (double check the existing system), as it is flexible in positioning sensors, and it can reach even to locations where people cannot come or are not allowed to go, or can only stay for a short period of time (dead corners). For high added value products it is even used as a triple check system.

WLAN, ZigBee and Bluetooth work in the 2.4 GHz range which leads to shorter distances than can be obtained with WiSensys system working in the 868 MHz frequency band.

The WiSensys system gives the opportunity to have near on-line access to the data. In comparison to a logging system, for the WiSensys system the moment of control may be placed much earlier in time, which may prevent f.i. high quality losses, in stead of deciding to not let pass a product shipment due to a bad quality. To have a multi purpose system, it is important that sensors can be replaced and installed quickly and easily.

The acceptance of wireless sensors is a problem. The customers do not know what products to use (ZigBee, smart, Bluetooth etc.). There is an educational task as supplier, and Wireless Value is looking for examples and proves in some applications. Once the products have proved it self, the insurance companies will accept it as well. Thereafter the product can be enhanced.

When monitoring in the open field, equipment power, cables and the move ability are a problem. With the standard sensors (pt100, 1000, moisture RH, T, 0-20V, 4-20mA), and a reasonable sampling frequency, the WiSensys system can operate over 5 years. Internally the sensor is switched on/off for 10-20 ms which leads to a long-battery life.

When using external sensors which need to be powered continuously, external power or larger batteries are needed. Depending on the application one must deal with the energy concept. Wireless Value even thinks of using mechanical energy for powering.

6.2 Temperature and RH monitoring in greenhouses

Companies related to control and automation in greenhouses sell (and sometimes produce in house) sensors and measuring systems for T, RH, CO_2, plant temperature, ion concentration, pH, EC, global radiation, wind speed, wind direction and rain. These sensor systems are hard wire connected to the data acquisition/control computer systems.

Especially for add-on products, not in connection to their standard controllers, (i.e. self supported monitoring systems, alarm circuits, gadgets for displaying measurements in the house of the grower, etc), they might have an interest in re-selling wireless measuring systems produced by external partners.

If they would decide to change completely over to wireless networks, it is reasonable to expect that they are able to develop (and will realize) their own sensors and measuring equipment for their standard process controllers. They will not rely on external partners if their core-business is concerned. Furthermore, it is doubtful that they will make such a move for the North European market or the North American market. In this respect they will act very conservatively, since the risk for production losses due to equipment failure is a hot issue. These risks are covered by insurance companies, which have a large influence in these kinds of decisions and have very strict rules on the quality of the equipment that they allow to be used. However, on the recently developed and new horticultural markets by f.i. Priva and Hortimax (i.e. Turkey, Mexico, China and Indonesia), where the infrastructure is not available as in the primary markets (Europe, Korea, and North America); they might turn to wireless solutions for a number of reasons:

- Wireless connections are a cheap alternative to hard wired connections.
- Products on these new markets have to compete on a basis of economics and prize.
- Wireless connected equipments can be delivered completely turn-key from the factory at the home base.
- Installation does not rely on local technical skills in these countries.
- Decisions for these markets are not so much scrutinized by insurance companies.

The application of plastic tunnels in Spain is a growing business. This could form an upcoming market through local dealers. Exporting equipment to e.g. China is hampered by the high risks that are involved of being copied and sold on the original home market of the product. This is especially the case, if the product has a high added value, a high novelty value, large economic prospects and high prize on the home market of the product (like climate computers and related equipments do). Turn key products and reselling third party products might prevent this from happening.

Priva, Hortimax and Hoogendoorn cover 80% of the global market in greenhouse automation. To really gain access to this market the insurance companies (Delta Lloyd, Interpolis) should be convinced of safety of wireless sensors. Some of the large companies are starting to look at wireless. Priva indicated to have a serious interest and is a large PMC.

Especially the smaller companies might be interested in applying third-party sensors and wireless equipment. Their annual turnover and profit is often too small to cover for expensive R&D on sensors and reliable (wireless) equipment, which makes them valuable product-market combinations for the wireless T en RV sensors. Potential companies are: B-E de Lier B.V, Beemster Elektrotechniek B.V., Boekestijn Elektrotechniek B.V., Bosman Topholding B.V., Brinkman Tuinbouw Techniek, Cogas Zuid B.V., Dalsem Tuinbouwprojecten B.V, Elektrotechniek L.J. van der Laan B.V., Hoogendoorn Automatisering B.V., Hortilux Schréder B.V., Hortimax B.V., Installatiebedrijf W.S. Janssen B.V., Kandelaar Elektrotechniek B.V, Lek Installatietechniek B.V., Nic. Sosef B.V., PB Techniek B.V., Priva B.V., Scherm Ned B.V., Van der Arend Beheer Westland B.V., Van der Hoeven Groep, and Wilk van der Sande B.V.

In greenhouses the WiSensys system has advantages over the current monitoring systems where often only one sensor per segment is used. With the system, more sensors can be placed to get information about the 3D spread of f.i. temperature and RH (seeking cold and hot spots, differences up to 4-5 C are observed). One of the main drivers to monitor T and RH in greenhouses is to save energy (gas), especially in the Northern countries like the Netherlands.

In the greenhouse market suppliers are conservative. Insurances play an important role herein. Priva has a large world-wide market, so how can we enter the world-wide market without Priva? There are many other companies, but this would involve contacting them all. Eijkelkamp and Delta-T already have their own products and are not likely to acquire a competing system.

The WiSensys concept aims at multiple generic interfacing options (like RS232, RS485, analogue, SD cards, data taker etc.). This makes more applications possible. However, a bottleneck is that some of the agriculture systems have a very odd interfacing structure (hardware/software level). If their market is small, Wireless Value is not likely happy to spend many working hours on developing an interface.

Experiments were performed in a cucumber greenhouse in Heerde. This grower (Wim Doorn, Heerde) was very positive about the WiSensys system. He could serve as an ambassador for the product. It would be best to write an article for a growers magazine (f.i. 'Onder Glas') in which the experiments and results of the PT-study as well as the instruments from Wireless value are presented.

6.2.1 Business proposition

In this paragraph, a business proposition for this product market combination: 'Relative Humidity and Temperature monitoring in greenhouses' will be given as an example. Within this proposition the new WiSensys configuration is compared to the current used setup by growers, the standard RH-T Monitoring boxes which are f.i. sold by Priva.

Current situation (Monitoring boxes)

A modern greenhouse in the Netherlands currently has an average size of around 4 ha. Its ground plane can have several shapes but a rectangular shape of say 175 m x 220 m^2 with a corridor/path over the longest axes can be taken as example. Currently each hectare is about the size of a climate controlled area, and for each area the grower uses a standard monitoring box as a RV, T-sensor. Due to wind and radiation influence, the side walls have effect on the local climate. Therefore, some greenhouses have a separate controlled area near to the side walls ('gevelnetwerk'). For our example greenhouse, a grower would need 8 monitoring boxes, one box for every hectare and one box for each side wall. The end-user price of a single monitoring box is about €2000 including installation (€16.000 in total, compared to WiSensys system for €2.800). Normally these boxes are connected to the climate management computer, which probably would lead to some extra installation/hardware costs as well, which is not taken into account.

New situation (wireless sensors)

In the Dutch greenhouses there is a trend to go to closed greenhouse systems. For these systems it is needed to monitor RH and T at least at three heights: near the fruits, near the crop (in between the plants) and near the top of the plants. In the standard (open) greenhouses this is not done, and monitoring at a single level is sufficient. To get an overview of the climate, the sensors could be placed in a grid of 5 x 5 sensors, taking into account placement at the corners, at the side walls, near the corridor, and in the crop. This would lead to a number of 25 sensors for the 4 ha greenhouse. For a closed (or semi-closed) greenhouse the sensors not near to the side walls would be needed in triplicate, which would lead to a number of 4x4 + 3x9 = 43. In case standard monitoring boxes would be chosen this would costs resp. €50.000 and €86.000 (without any quantum discount). This investment is not likely to be done by growers. In case this system was built up with WiSensys components (RV, T-sensors €275 + 1 RS485 host system €600) it would costs approximately €7.475 and €12.425. Based upon the test-results from the cucumber greenhouse in Heerde it is estimated that 1 host system (receiver) is probably sufficient for 4 ha (175 x 220 m^2) but this depends on the positions of sensors, the shape and local situation (compartments) of the greenhouse. In some cases maybe 4 receivers would be necessary. Installation of cabling is then needed to power and connect these receivers.

Incentives for buying the new system

Existing open greenhouse systems

Growers having standard open greenhouse systems that already have invested in a number of monitoring boxes are not likely to throw away this system and buy a new one. However, buying the new wireless system as an extension to the current monitoring boxes may give the grower opportunities to get denser and local information of his micro-climate, making him very flexible in were to position the sensors, for a relatively low price. This approach fits into the trend that modern climate management is more and more relying on modeling and input from sensors. This is all driven by the need to use as less energy (gas) as possible from an environmental point of view. Some standard growers may even try to move towards semi-closed growing systems where monitoring is needed to detect cold and wet spots to prevent from crop diseases.

(Semi) Closed greenhouses

In the Netherlands the ambition of the government and the horticultural community currently is to move towards close or semi-closed greenhouses (PT, 2008). The area of closed or semi-closed greenhouses in the Netherlands will grow from 100 ha in 2007 up to 2.500 ha in 2020. Since the most of these greenhouses will be newly build, there is a good opportunity to sell the new wireless systems, since growers then have the possibility to make new investments and choices for new technologies. It is wise to follow the developments in this field and maybe to join the several initiatives (f.i. demonstration greenhouses).

Benefits/Disadvantages

The next table gives an overview of advantages and disadvantages of the WiSensys system compared to standard monitoring boxes.

WISENSYS	Standard Monitoring box
Batteries need to be replaced regularly (Question: With a requested battery lifetime: 1 year, what is the maximum achievable cycle time?)	**Power is hardwired**
Not ventilated (may lead to errors in case of high radiation)	**Ventilated (Sownet wireless system is ventilated as well)**
Standard sensors have no protection from direct radiation	
Easy installation of the sensors, which can be done by grower quickly	Installation normally via installer (extra costs)
Standard sensors must have a different housing (reflection)	
Flexibility in placement of sensors (in between crop is possible when receivers have a strategic high position), no cabling is needed for sensors (less cable costs)	(nearly) fixed position due to wiring
Placement of receivers needs wiring and installation (up to 1 per ha. estimated)	**No receivers needed.**
RH and T response is slightly quicker than the monitoring box	
Accuracy of RH and T is similar to the monitoring box	
Extension of the system with more sensors is easy and relatively cheap (cost of 1 sensor). Extension costs about €300	Extension costs € 2000
(not yet) NKO-certificate	**NKO-certificate**
The data reliability is high (data losses < 1-2 %) in case sensors are within reach (about 60-80 m range when there is reasonable line of sight	**Hard-wired, no data losses**
Interfacing with management computer is not yet available	**Easy interfacing, available on all climate computers**
Growers have no experience with these sensors, so trust in the sensors is something to work on	**This is common practice**

6.3 Temperature measurement in storage housings

The storage of agricultural products is one of the major possible application fields for wireless sensors. This is especially true for the huge market of the potato production. For the storage of potatoes, onions, crops, vegetables and fruits, it is necessary to different physical effects like f.i. the temperature and humidity. The professional storage of the products (potatoes, onions ...) is reasonable and needed because of the following reasons:

- It is possible to sell the products at a more optimal time.
- The price does not depend on seasonal changes. With the storage of the product it is possible to earn more money.
- It is convenient to have a storage place near the field to be able to conserve the products right after the harvesting.
- Useful to avoid infections.
- The loss of weight and quality is reduced.

For the storage of products it is necessary to notice that the products are living products that need energy for living. This energy is produced by the own cells. During the process of the energy conversion carbon dioxide and water that raises the humidity is generated. The process results in a loss of quantity and quality. Storages offer the possibility to control this process and to reduce the loss to a minimum. This is a reason for the usage of temperature and humidity sensors, to be able to control and document the storage process. [Agro].
The following storage types are the ones that are used the most:

Figure 54. Box storage [Agro], bulk storage [Mooij], silo storage [Silo].

During the storage time the products can be treated as follows:

- Drying → avoids the spreading of diseases, cures wounds.
- Cooling → avoids germination and infections.
- Ventilation → decreases carbon dioxide, prevents condensation and temperature changes.
- Moistening → avoid loss of weight and dents.
- Heating → avoid colour change or the creation of sugar.

Table 10. Storage temperature.

Table potatoes	6 - 7 °C
Potatoes for fries	7 °C
Seed potato	3 - 4 °C
Onions	0 - 2 °C
Carrots	0 - 1 °C
Celeriac	0 - 1 °C

Table 10 shows typical storage temperatures for different products. In the following section, the amount of farms needing storage systems will be shown. Therefore, only the storage of potatoes will be taken into account.

The system was used to monitor the temperature at which potatoes ripe in the field. They should stay under 20 °C for being a good product to be able to use them as French Fries.

6.3.1 Business Proposition: Potato Storages

Current situation

Typicaly the product 'potato' cannot be delivered directly from the field to companies for further processing. Thus there is a need for potato storages at the farmer. For shorter time periods (1 to 3 months) the potatoes are directly stored on the field in the most cases ('Kartoffelmiete'). For longer storage periods indoor potato storages are used, with or without cooling.

Potato storages with cooling have a typical unit size of 1000 to 2000 tons of potatos. The temperature is measured with about 5 to 10 sensors, which are connected by wires for data acquisition. The sensors will be installed when the potatos are already in the storage. The sensor are fixed at metal bars, typically the temperature is measured in a depth of about 0, 5 m to 1,0 m.

In Germany there are about 63.900 farms (2007) harvesting potatos. The field sizes vary strongly from very few up to more than 100 ha. Reliable numbers of the market situation with respect to the potato storages are not available (as for example: Deutsche Landwirtschafts Gesellschaft, Zentrale Markt und Preisberichtstelle, Statistisches Bundesamt). According to an estimation from Mr. Gerolf van der Zee (AgroVent) about 25 to 30% of the farms use cooling in their potato sotrages.

The price for a sensor including a 10m cable is about 100 € (company Mooij). 12 temperature and 4 humidity sensors are coupled to an electronic box, which sends the corresponding data via a bus system to a PC taking care about the control. The price for the box is about 400 €, the installation is estimated to be done in 2 to 3 hours (ca. 200 €). The company Mooij installs about 150 sensor systems a year. The company AgroVent has the same market volume (about 1500 a year), the electronic. The prices are similar as compared to Mooij, the electronic box is more expensive (ca. 1.500 €,) but includes more functions.

New situation (wireless sensors)

The improvement of wireless data transmission has now offered options for applying such systems in storages. So far no wireless sensors are available in the market for potato storages. Since food tracking and quality control in the complete food production chain gain increasing importance, the pressure to implement cooling systems in potato storages also increases. This goes along with the implementation of sensor systems, mainly temperature and humidity. Moreover, expected changes in the climatic conditions might speed up the need for the implementation of these technologies.

As compared to the existing (cable-based) sensors, wireless sensors would be more expensive since an adapted sensor housing and metal bar might cost about 200 €. The price for the base station (about 800 €) is comparable.

Incentives for buying the new system

The implementation of wireless sensors could be profitable for the farmer in the case of a new potato storage. In this case the costs for the wiring would not occur. However, it would be more interesting if the price of the sensor unit could be in the range of the existing systems (ca. 100 €).
However, the flexibility with the wireless sensors is better: The position of the sensors can be changed more easily, the number of sensors can be changed without external technical support, furthermore there is an option to use one base station for more storage units.

In the case of existing (cable-based) solutions it is not expected that the system will be replace by wireless systems.

Benefits/Disadvantages

The table summarizes advantages and disadvantages of cable-based and wireless sensors for the application in potato storages.

Temperature-controlled potato storage with cable-based sensors	Temperature-controlled potato storage with wireless sensors
The sensors are adapted to the application in potato storages.	The sensors have to be extended by a metal bar in order to measure the temperature or humidity in a depth of 0,5 to 1,0 m.
The number of sensors cannot be extended easily.	**Position and number of sensors can be varied.**
Cable complicates the storage process.	**The integration of the sensors can take place faster.**
Cable might be damaged during potato input or output.	**There are no cables to be damaged during potato input or output.**
Sensors can be found easier.	The probability to loose a sensor is higher.
	Costs for cables and installation is reduced.
	Depending on the position of the base station, more than 1 potato storage unit might be supported.
Power is hardwired.	Batteries need to be replaced regularly.
Installation normally via installer (extra costs).	**Easy installation, can be done by grower quickly (for sensors).**
Hard-wired, no data losses.	A few percent of data could be lost.
Interface for control system exists.	Interface to control system has to be adapted.

6.4 Monitoring on mobile platforms

This survey is related to market of agricultural machines (crop production) and transportation (delivery chain). This market has got double-digit rates of growth in the last years.

For this market it could be possible to use sensors for logging applications. To be able to use the sensor for logging the temperature or the humidity while driving, no change has to be done to the hardware. The logged data can be, for example, analyzed afterwards to check the climate during the last trip. This could be an easy way of accessing a huge market with lots potential customers and a high growth rate.

During the Agritechnica 2007 companies in the fields of storage and agricultural equipment had been interviewed for this market survey. These companies have been asked about their interest of integrating WiSensys sensors into their product or to sell them as a piece of their product range. The result is that some of the companies, in the field of storage, are very much interested in integrating the WiSensys sensors into their products. Therefore, the protocol of the sensors needs to be adjusted, in a cooperation of Wireless Value and the companies, to match the existing protocols of the control systems. The companies in the field of agricultural machines are only interested in using the sensors during the development of a new product. The complete overview of the interview can be found in the Appendix 0.

Due to the large market of agricultural machines (see section 3.5.2) a first step into this business might open windows of opportunities to direct cooperation as well as to indirect options (sensor companies, farmers). Applications are testing of new machines, testing for service applications or time-limited applications of sensors. New laws (as for example with respect to boundary conditions for spraying chemicals) might push wireless sensor developments for continuous or limited quality control.

Agricultural companies with low or medium knowledge level in electronics and software are possible candidates (Strautmann). However, also larger companies showed interest (Agrocom, Claas, and Krone). A consortium of six agricultural companies will probably implement a centre in ISOBUS (standard bus systems in agriculture) at the University which might offer further opportunities. The companies are Amazone, Krone, Grimme, Rauch, Lemken and Kuhn.

Existing contacts of the University of Applied Sciences Osnabrück to several companies will also be used for further information about the systems, where first tests might be performed by student projects.

7 Conclusion

Due to regulations and the need to reduce environmental impacts, monitoring plays an important role in agro food production chains, a role which is growing ever year. Monitoring takes place on several spots in the chain (in open field production, greenhouses, storages, during transport, in distribution centres, in retail). The type of parameters to monitor, depend largely on the type of products (crop/flowers) or the phase or stage of the product. The market for this type of innovative products is rather wide. The problems associated with it, like the need for many wires and powering, and the lack of flexibility, drives people to look for alternatives like wireless sensors. This study focussed on the evaluation of the market perspective and technical feasibility of the application of such a wireless sensor system (WiSensys) for high value horticulture food and flowers chains.

The scientific challenges for this study were the reliability and performance of this low-power wireless sensor network under the strong fluctuating RF propagation circumstances (damping) in agricultural environments, which influences strongly the reachable distance, especially in for instance greenhouses and buildings. This study therefore explored the reliability of the system under a number of practical situations. It further investigated the market perspective for the system. As such it tried to find those applications that would be the easiest to sell into the new market. Further, this study showed which enhancement or adaptations should be made to the current system, and which sensors are needed for the new markets. An estimate will be given about the expected market volume, and the potential partners and competitors will be mentioned.

As a main conclusion from this study we can say that the WiSensys system has large potential to be applied in agriculture. A large number of possible applications do exist, however we recommend focusing initially on temperature and relative humidity monitoring in greenhouses, and temperature monitoring in potato storages. The main reason for this is that the current WiSensys system can be applied here without comprehensive adaptations, that there is a clear demand from the sector, and a large market. No direct control, other than via manual intervention is needed. The system can be used next to other systems to control or monitor the process. Many advantages can be found due to wireless, the dense sensor configuration, and reasonable range in indoor situations. Compared to potential competitors in this sector, a strong point is that the WiSensys system has proven to work well under these conditions in practise. However, during the experiments some general observations have been made. Currently the system has no user-friendly feedback facility to indicate that there is a data communication loss between sensor and base station, as f.i. when a sensor is out of range or has an empty battery. Under some conditions there were starting problems when batteries were replaced. Some sensors had a bad battery contact, which lead to a full stop of the sensor operation. These remarks are only of minor importance since they can be easily mended.

Greenhouses: The distance that can be covered in a greenhouse depends on the total amount of biomass inside the greenhouse and the placing of the individual sensors and the base station. For a high density crop (cucumber) distances can be obtained reaching over 100m, providing that the pathway is only blocked by a limited amount of crop. For low density crops (lettuce, flowers etc.) longer distances (up to 250 m) can be obtained. A good position for the base station is a high position in the top of the greenhouse, over looking all plants. Sensors can be placed inside the crop, but preferably near the top level of the plants. Under no circumstances should the pathway be blocked by more than 25 m of crop to be well away from the maximum through-the-crop distance observed for tomato of 50-60 m. The transmission may work through glass windows, but metal (pillars, doors and walls) will block the signal drastically. The experiments were limited to the situations chosen for the experiments. In practise many type of greenhouses and set-ups can be found making every situation different. The best thing is to optimise sensor placement by testing its performance at installation time.

Although the WiSensys system is very well suited for this application, little, but a few adaptations are to be made. For greenhouse application, the sensor nodes should be protected from direct radiation by sun-light by placing them into a white box and/or placing a screen above the sensor. It is wise to get an NKO type certificate for the system. The system should be interfaced with the monitoring and control systems of the several greenhouse suppliers, for which however no standards are available. On the longer run the system might be expanded to become a water, phyto- or micro-climate monitoring system by introducing new sensors like: CO_2, plant temperature, ion concentration, O_2, pH, global radiation, air speed, soil moisture and EC. Most of these sensors are available as OEM products; however they often need an external (interrupted) power supply and are more costly than the standard used sensors.

The area of greenhouses in the Netherlands is large (about 10.000 ha). Presuming that growers want a few (5-10) sensors per ha. the total selling volume in the Netherlands could go up to 100.000 sensors. It is expected that the larger growers (size about 10 ha) will invest in this equipment when building new greenhouses. Existing smaller growers will buy the system as an extra option, having benefit from the easy wireless installation. The market world-wide could be even larger. Companies like Priva are entering the booming business for new horticulture production areas like in Mexico, China, Indonesia and the southern European countries.

Storages: The test measurements and discussions showed a potential for the application of wireless sensors in storages, such as for potatoes. From the potato experiment in a storage hall it was concluded that the temperature can be measured if the position of the sensor is pre-selected. Low-frequency measurements for temperature and humidity are important for the quality and thus are major control parameters. The range has to be checked for individual cases, however, for most typical situations the availability has been tested successfully. A sensor checking the availability of the signal would be helpful for the first installation or continuous checks. Buildings seem to obstruct the direct signal enormously. A rule of thumb is that a single wall reduces the distance with a factor 2. In metal boxes or storage houses, the reflections are large, and eventually the signal will get out. The antenna should be kept upright, and typical distances in buildings are 80-90 m.

For application in potato storages the system should be adapted mechanically. Preferably the long metal temperature sensor insertion needles must be fitted to the housing directly or via a cable.

Due to the large market volume for potato storage the business volume is expected to be in the range of several thousands (best practice examples would be helpful for direct or indirect marketing). Intra-farm applications might go along with this (redundant temperature checking as for example). The market for mobile machines will be small in the beginning; opportunities might come up with successful implementations.

Other applications

A number of other potential applications came onto the second place, which are:

- monitoring on mobile platforms (large market),
- storage computing for silos,
- sensor activated control of distributed equipment in greenhouses,
- intra-farm equipment (redundant safety),
- transport monitoring and logging ('chip in the crate'),
- phyto-monitoring (indoor/outdoor),
- water and nutrient monitoring in substrates or potted plants (indoor/outdoor), and
- water and fertilization monitoring in outdoor soil based crops for irrigation.

Since these have a good market perspective, it is good to pursue these as well. However, they score slightly lower because either external sensors are needed, the market and applications are rather dispersed, or they directly have demands for on-line control. We advise to enter these markets in a second step, for instance after first trying out the system under practical circumstances, finding good ambassadors as well as partners that are interested to sell the products in these markets. These partners are the ones that already sell a large number of instruments, sensors and controllers in the agricultural markets for greenhouses, agricultural machinery (example: Strautmann), storage and transport, and themselves having a low-level knowledge in electronics and measurements. This market is rather diverse and has many players, of which most of them can be found on the Hortifair (Amsterdam) and the Agritechnica (Hannover).

The experiments with wireless sensors in agricultural equipment showed good results. The information needed for development or service purposes – having a look at the existing sensors – might be the temperature. For (mobile) outdoor applications (outdoor potato field) the mechanics of the sensors should be adapted to make them more robust against weather influences (dust, rain...) and vibrations.

Competitors: Although world-wide there is a large trend towards the use of wireless sensors for agricultural production, in the two segments reported there are nearly no competitors. The applications that can be found are mostly in outdoor farming devoted to climate monitoring (weather stations, Eijkelkamp and others) and irrigation scheduling (Sownet, Netafim, Decagon, Crossbow, DeltaT). Also a number off research experiments are reported (LOFAR, FLOW-AID, WASP...). The company Pessl Instruments can be seen as a competitor. For greenhouse applications, Sownet works on RH, T wireless sensors, and Growlab sells the Sensiplant, a wireless soil moisture sensing system for f.i. indoor mobile applications.

Partners: For these two main applications ambassadors were found. The WiSensys system – with 100 sensing points – was tested in a greenhouse in Heerde (NL), at a cucumber grower (Willem Doorn). This grower was very happy about the system, since he could obtain good and dense information about the micro-climate inside the greenhouse, which made it possible for him to manage his climate computer better, and thereby possibly reduce his energy use. It would be wise to aim at a publication about this test in a grower's magazine (f.i. 'Onder Glas'). The system could be sold by the larger greenhouse supplier companies like Priva, Hoogendoorn Automatisering and Hortimax, which already have shown their interest. In case these wouldn't go for it, a larger group of smaller suppliers have to be contacted. Regarding monitoring in storages, the larger potato farms (as for example in 'Emsland'), could be the ambassadors. The system was already tested at Brüggeman in Bramsche (Germany). So far wireless sensors in storage are not used. There is the opportunity to start with this business. In order to take a step into this market the three following approaches to the market might are recommended:

- application of a system at dedicated farms for storage of potatoes (interested farms in the Emslad/Germany are known); creating 'best practice' examples;
- cooperation with suppliers of sensors for agriculture (see contacts of the Agritechnica);
- bring test sensors to companies for agricultural machinery (large market volume, multiplication effect; examples: Strautmann, Krone, Claas).

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9 Appendixes

Minutes of the kick-off workshop

Wednesday, March 07, 2007, 10h-12h, WUR, Wageningen
Attendees: Paul Eggen – Eucan; Arno Ruckelshausen – FHO; Jouke Miedema – Wireless Value; Jean Helleboog – T+M Systems; Martin van den Brandt – T+M Systems; Tom Cornelissen – (Oost NV); Jos Balendonck – WUR; Bart v. Tuijl – WUR; Jochen Hemming – WUR (minutes).

There is an agreement that we are going to sign an IPR agreement and non-disclosure agreement (proposal will be sent by Jouke). Agreement between WUR, FHO and Wireless value will be sufficient because others have already signed such an agreement. Jos will discuss legal issues commented by Jouke with our legal department
In the WiSensys system the sensor is (may be) not powered by the WiSensys system. There are solutions to power the sensor externally. The existing system is designed for data logging and monitoring, not for critical time controlling aspects. System is already used in e.g. restaurants (temperature), food storage places (temperature and humidity). T+M Systems is distributor in the Benelux, Orbi-Solutions is a reseller of the WiSensys system. Wireless value decided to include the top level distributor.

Discussion after presenting the work plan

Report should be clear to the point. Identify some objectives. Long text is not desired. More like tables and graphs including + and – signs. Quick scans should clearly include wishes and demands from an agriculture point of view.
Time scale: desired by Wireless Value to have the result before the summer (end of June).
Suggestion by Jos: have the final workshop before the holidays but hand over the report after the summer holidays. This is agreed by Wireless Value. If a step 5 project is desired it should be prepared not to late this year.
1st of April could be the starting point officially. New type of sensors should be identified but the time is to limited to test these sensors. We should use what we have at them moment.
Question to give answer on: Who is the system matching with existing systems?
Another point: How useful is the data gathered by the system by the end-user?
Question: maybe it is good to have the system for longer than one day but e.g. have it for 2 weeks. WUR already has a system and can use this one.
Install device in the greenhouse and get some reactions from the grower. (Only one example).
Wireless systems/Eucan will provide a test set for some weeks to FHO.
WUR (PRI) will be the project leader – there will be one contact person (to be identified). FHO will work under the lead of WUR. At the end of the project will be two bills (one from WUR, one from FHO).
FHO will co-operate with local agricultural department. FHO: might do work in the open field sector, further up in the agro chain. WUR: more horticultural crops, primary production.
At the focus workshop we should make some suggestions about work packages and suggestions how to allocate the work between FHO and WUR.
WUR and FHO are allowed to be referred to about the project by the project partners. Also the other way round (WUR may mention about the project to third parties) is agreed on.
Financing scheme: I&I (Oost NV), on behalf of the Euregion, pays at the end of the project (takes about 6 weeks).
Jos will try to reorganize the offer by PRI so that there will be no bill before the end of the project (preferred at the end of June).
FHO has to provide some text to be added to the proposal.
FHO should prepare a 'draft' offer, PRI already has defined one.
There is a need to have 2 SME's from the region. At the moment there is only one. Orbi-Solutions might be an option? Will be discussed by the EUCAN, Wireless value T+M after the meeting.
It is asked to present in the focus meeting details of how we will perform the market survey (what techniques are used).

Minutes of the second workshop (Quick scan results)

Wageningen - June 14th, 2007

Attendances: Jouke Miedema, Jean Helleboog, Bart van Tuijl, Theo Gieling, Andreas Linz, Arno Ruckelshausen, Kai-Uwe Wegner, Martin van de Brand, Michel Kockelkoren, Wilfried Niehaus, Jos Balendonck (minutes).

Market Survey and Feasibility Study approach (Balendonck)

Wireless Value doesn't want to do Time Critical Automatic Control. It focuses on information passing to the ones that are responsible for taking actions.

The dealer is European, but there is an ambition to seek a worldwide market.

In general the mentioned suppliers (like Priva) do not deliver products to the Delivery Chain (container automation). Here other companies are active like f.i. Imtech and other system integrators.

The WiSensys system is often used as a secondary control system (double check the existing system), as it is flexible in positioning sensors, and it can reach even to locations where people cannot come (dead corners). For high added value products it is even used as a triple check system.

In greenhouses the WiSensys system has advantages over the current monitoring systems where often only one sensor per segment is used. With the system more sensors can be placed to get information about the 3D spread of f.i. temperature and RH (seeking cold and hot spots, differences up to 4-5 C are observed).

The chains must be described more in detail (it is too generic). Who are the customers and users? It would be nice to look for legislative incentives from customers.

More figures about world markets must be added.

A broader view is needed, f.i. outdoor applications lie in: recreation, energy production.

Michel tells that his view of the market is according to the line: Seeds, grower, trade, and retailer. Each segment has its own market strategy and quality strategy. Growers would like a complete and turn-key system without bothering too much with details. Seed companies would like guarantees about the data. ISO is important in trade. It may lead to different propositions and value packs for the several segments. Theo explains that there are many ways of looking at the market.

Greenhouses (Gieling)

In the greenhouse market suppliers are conservative. Insurances play an important role herein.

How can we enter the world-wide market without Priva? There are many other companies, but this would involve contacting them all. Eijkelkamp and Delta-T already have there own products and are not likely to acquire a competing system.

WLAN, ZigBee and Bluetooth work in the 2.4 GHz range which leads to shorter distances than can be obtained with WiSensys concept. Priva (de Zwart) has confirmed this for a greenhouse experiment done in Bleiswijk.

The WiSensys concept aims at multiple generic interfacing options (like RS232, RS485, analogue, SD cards, data taker etc.). This makes more applications possible. However, a bottleneck is that some of the agriculture systems have a very odd interfacing structure (hardware/software level). If their market is small, Wireless Value is not likely happy to spend many working hours on developing an interface.

Open Field Horticulture and Horticultural Production Chains (FHO)

Wilfried showed a potato storage farm experiment. Buildings seem to obstruct the direct signal enormously. The antenna should be kept upright. Typical distances in buildings are 80-90 m. Rule of thumb; a single wall reduces the distance with a factor 2. In metal boxes or storage houses, the reflections are large, and finally the signal will get out. It works from within a refrigerator.

In the open field for monitoring equipment power, cables and the move ability are a problem.

With the standard sensors, and a reasonable sampling frequency, the WiSensys system can operate over 5 years (pt100, 1000, moisture RH, T, 0-20V, 4-20mA). For external sensors however this is not guaranteed, due to higher power uses. Internally the sensor is switched on/off for 10-20 ms which leads to long-battery life. For continuous operation external power or larger batteries are needed. Depending on the application one must deal with the energy concept. Wireless Value even thinks of using mechanical energy for powering.

An application was mentioned where wireless sensors were dropped from a plain.
The system was used to monitor the temperature at which potatoes ripe in the field. They should stay under 20C for being a good product to be able to use them as French Fries.
Idea: Can the product be buried in soil, and if so, how deep can it be buried and how does the readout distance is influenced?

Discussion and selection of PMC's

Options:
1. Small companies, all kinds of applications (closed horticulture)
2. Choose one large supplier (f.i. Priva, Hoogendoorn, Hortimax)
3. Sensors on machines (outdoor)
4. Storage of potatoes

Points mentioned in discussion

Roses in England.
Wireless versus/logging in relation to moment of control.
Plastic tunnels in Spain (upcoming market through local dealers)
Acceptance of wireless sensors is a problem (Jouke).
The customers do not know what products to use (ZigBee, smart, Bluetooth etc.) There is an educational task as supplier. We are looking for examples and prove in some applications. 'We want to pick the low hanging fruits'. Once the products have proved it self, the insurance companies will accept it. There after the product can be enhanced.
Advantages: deleting cables (costs), measure where people are not allowed to go, or only for a limited amount of time.
Spraying Booms?
Criteria for business development:
Build confidence fro wireless sensors
Does it solve a problem for the customer? Has it added value? Does it save costs?
Define the business case
Built a reference list, and find ambassadors for the product (f.i. Emsland).
Free publicity (Inspire and Innovate website). Short movie on television?
Currently there is no alarm once a transmitter gets out of range. Wireless Value has already found a solution for this.

Actions and Planning

The project ending is planned by the end of august.
WUR and FHO will proceed with the study and will look for detailing the study in the area of the 4 mentioned PMC's.

Field tests

The demonstration/tests should be done at recognized farmer locations. WUR/FHO will look for the best options.
Consortium will be invited at field days.

Round table

Next meeting to be held when final results and draft report are available.
Jos will inform Jouke about possibilities for KNO certified testing of the product in the Calibration Lab of WUR
Jos will try to establish contact with the VWA in their building to see if they can inform Jouke about Food regulations and instrumental requirements.

Minutes of the final workshop

Wageningen - October 1st, 2007
Attendances: Jouke Miedema, Jean Helleboog, Paul Eggen, Theo Gieling, Arno Ruckelshausen, Jörg Klever, Michel Kockelkoren, Jos Balendonck (minutes).

Market Survey and Feasibility Study approach (Balendonck)

Remarks:
Exact data from Bart about the experiments must be added to the report. The full set-up must be described.
It is o.k. to focus on cheap moisture sensors with an accuracy of 5%.
Jos will ask what information from the other LNV-research may be used for PR.
WUR wants to assemble a paper on the experiment.
How many sensors are needed per m2?
What are the buying issues for a customer?
How much may it cost?
For mobile growing systems there may be chances for a product-market combination.
Theo has established a contact with Ad the Koning and Westland Energy.

The consortium will be invited to visit the greenhouse test in Heerde (Bart van Tuijl).

Market Survey and Feasibility Study approach (Ruckelshausen)

A contact was established with Krone/Klaas about harvesting.
Wireless water monitoring in grains was studied.

Wireless Value has some initial questions:
Is the current system good for agricultural application?
If yes, for what applications can the product being sold in the easiest way?
Who are ambassadors for these applications?
Where should the current system be adapted?
What will be the business volume?
Who are the competitors?

There is money available to perform the adaptations. Who needs to perform these adaptations?
The report should give information on the investments for the market.
When visiting companies, the consortium will be presented as Wireless Value.

The consortium wants the results being exposed in articles. WUR can make articles for 'Onder Glas', 'Oogst', or the FlowerTech.

FHO will invite Jouke to the Agritechnica in Hannover (13-17th November).

Jos will contact the consortium about PR via Inspire and Innovate.

The final discussion about the final report will be organised in Osnabrück.

Visit Agritechnica 2007 (Summary in German)

Jörg Klever, University of Applied Sciences Osnabrück

At the Agritechnica 2007 in Hannover Jouke Miedema (Wireless Value), Arno Ruckelshausen and Jörg Klever (FH Osnabrück) hat some meetings with companies in the fields of storage and agricultural equipment. This appendix gives information about the meetings and some additional general information.

Auf der Landwirtschaftsmesse Agritechnika 2007 waren mehrere Firmen vertreten die Komponenten zur Lagerung anbieten, wie zum Beispiel Lüfter, Kühlanlagen und Sensoren. In Gespräche mit den Firmen wurde besprochen ob sie Interesse daran haben kabellose Sensoren von WiSensys in ihre Produktpalette mit aufzunehmen oder in ihre Produkte zu integrieren.

Lagerung

Firma		**Ansprechpartner**		
	GAUGELE GMBH		Dipl. -Ing. Sven Pahl	
	Osterseenstraße 31		Dahlenburger Weg 3	
	D 82393 Iffeldorf		D 29584 Himbergen	
Tel:	+49 (0) 8856/2065	Tel:	+49 (0) 5828/1590	
Fax:	+49 (0) 8856/9895	Auto.Tel	+49 (0) 171/2349678	
	www.gaugele.de		Bereich	Softwareentwicklung

Produkte der Firma

Agrar- und Klimatechnik für Kartoffel, -Zwiebel, -Gemüse

Gesprächsthema

Beim Gespräch mit Herrn Sven Pahl stand im Mittelpunkt, was alles gemacht werden muss, um das kabellose Datenübertragungssystem in die Produktpalette von GAUGELE zu Integrieren. Dabei ging es zum einen um die Software- Seite und zum anderen um das Sensorgehäuse. Die Firma GAUGELE würde das Sensorgehäuse so anpassen, das es zu ihren Produkten passt (Form, Farbe und Beschriftung).
Ein weiteres Gesprächsthema war der Preis für die kabellosen Sensoren.

Aussichten

Die Chance für eine Kooperation zwischen WiSensys und GAUGELE sind sehr gut. Beim Gespräch sagte Herr Sven Pahl, dass die möglichen Stückzahlen zwischen 800 und 1200 Sensoren pro Jahr liegen könnten.

Firma		**Ansprechpartner**
	Mooij	Maarten Mooij
	Stationsstraat 142	Director
	NL 5963 AC Hegelsom	
Tel:	+31 (0) 77 3275045	
Fax:	+31 (0) 77 3275046	
	www.mooij-agro.nl	

Produkte der Firma

Belüftungs- und Trocknungsanlagen für Agrarprodukte wie Kartoffeln und Zwiebeln

Gesprächsthema

Beim Gespräch mit Herrn Maarten Mooij kam heraus, dass sie sehr skeptisch gegenüber der Stabilität des Sensorgehäuse sind. Sie meinten, dass der Krafteinsatz beim Einsetzen der Sensoren sehr hoch ist und deswegen ein stabileres Sensorgehäuse benötigt wird.

Aussichten
Die Chance für eine Kooperation zwischen WiSensys und Mooij ist schlecht abzuschätzen. Wenn eine Zusammenarbeit zustande kommt, würde die Firma Mooij ca. 1000- 2000 Sensoren im Jahr benötigen.

Firma		**Ansprechpartner**	
	Pfalztechnik		Dipl.-Ing. (FH) Antje Kuhnert
	OT Kiesdorf, Auengrund 2		Kundenbetreuung - Verkauf
	D 02899 Schönau-Berzdorf		Berzendorfer Straße 22g
Tel:	+49 (0) 3 58 23 85 807		D 02827 Görlitz / Tauchritz
Fax:	+49 (0) 3 58 23 85 809	Tel:	+49 (0) 35822 3127-16
	www.pfalz-technik.com	Fax:	+49 (0) 35822 3127-27

Produkte der Firma
Mobile und stationäre Kaltnebenanlagen

Gesprächsthema
Beim Gespräch mit Frau Kuhnert war das Interesse an den kabellosen Sensoren sehr Hoch. Aber sie kommt aus dem Bereich Verkauf und deswegen wird sie die Angelegenheit an das Technische Personal dieser Firma weiterleiten.

Aussichten
Die Firma Pfalztechnik wird nach Meinung von Frau Kuhnert wahrscheinlich eine Basisstation mit zwei Sensoren zum Testen bestellen (Demo- Ausrüstung).

Firma		**Ansprechpartner**	
	Supertech- Agroline		Karl H Berger
	Brefeldweg 1		
	D 48291 Telgte		
Tel:	+49 (0) 2504/3947		
Fax:	+49 (0) 2504/72277		
	www.supertech-agroline.de		

Produkte der Firma
Temperaturmesssysteme für Getreidesilos und Schüttgutlager, Feuchtemessgeräte im Einsatz bei Heu- und Strohballen, Getreidefeuchtemessgeräte

Gesprächsthema
Beim Gespräch mit Herrn Berger wurde besprochen, wo die sinnvollsten Einsatzgebiete der kabellosen Sensoren bei den Produkten von Supertech- Agroline sein könnten Dabei ist herausgekommen, dass sie für die Temperaturüberwachung bei den Lager- Silos nicht eingesetzt werden können, weil an den Sensorboxen von WiSensys nur ein Sensor angeschlossen werden kann. Die Messsonden von Supertech Agroline sind 2,5 -5,5m lang und haben 2-4 Temperatur- Sensoren (In verschiedene Höhen) integriert. Das würde bedeuten, dass an einer Messsonde 2-4 Sensorboxen angebracht werden müssen. Das währe sehr kostspielig und deswegen würde die Firma lieber ein anderes System einsetzen.

Die kabellosen Sensoren von WiSensys könnten aber bei der Erfassung der Wetterdaten eingesetzt werden.

Aussichten
Eine Zusammenarbeit zwischen WiSensys und Supertech- Agroline ist sehr unwahrscheinlich, weil der Vorteil von kabellosen Sensoren bei der Erfassung von Außentemperatur und Luftfeuchtigkeit sehr gering ist und deswegen den höheren Preis nicht rechtfertigt.

Firma		**Ansprechpartner**	
	Pfeufer GmbH		
	Mess- und Prüfgeräte		Dipl. –Kaufmann Lothar Pfeuffer
	Flugplatzstrasse 70		
	D- 97318 Kitzingen		
Tel:	+49 (0) 9321 9369 15		
Fax:	+49 (0) 9321 9369 50		
	www.pfeuffer.com		lothar@pfeuffer.com

Produkte der Firma
Temperaturmessanlagen für Schüttgüter in Lagerhallen (Getreide), Feuchtemessgeräte für Getreide

Gesprächsthema
Beim Gespräch mit Herrn Pfeuffer stand im Mittelpunkt, wie viel die Sensoren kosten und welche Datenübertragung verwendet wird. Dabei war dem Herrn Pfeuffer wichtig, wie zuverlässig die Sensoren sind. Außerdem war die Energieversorgung der Sensorboxen ein Thema, wobei die Betriebsdauer und die Kosten der Batterien wichtig waren.

Aussichten
Die Chance für eine Kooperation zwischen WiSensys und Pfeuffer ist schwer abzuschätzen. Aber die Firma wollte höchstwahrscheinlich ein Demoset bestellen um zu testen, ob die Sensoren für ihre Produktpalette einsetzbar sind.

Firma		**Ansprechpartner**	
	Agro Vent System		Berend Volders
	Tragieweg 18		Bereich:Verkauf
	NL 8304 BA Emmeloord		
Tel:	+31 (0) 527 636 150	Tel:	+31 (0) 622402405
Fax:	+31 (0) 527 636 155		
	www.agrovent.nl		volders@agrovent.nl

Produkte der Firma
Lüfter, Lüftungsschächte, Schaltschränke, Raumkühlung

Gesprächsthema
Herrn Volders hatte nur wenig Zeit für ein Gespräch, aber das Interesse für die kabellose Datenübertragung war vorhanden

Aussichten
Die Aussichten über eine Zusammenarbeit zwischen WiSensys und Agro Vent ist nicht abschätzbar, weil das Gespräch zu kurz war.

Firma	
	Kälte herberholz Klima
	Steinkuhler Weg 10c
	D 59505 Bad Sassendorf
Tel:	+49 (0) 2921/55462 + 51860
Fax:	+49 (0) 2921/53141
	www.kaelteherberholz.de

Produkte der Firma
Klimaanlagen, Kühltechnik

Gesprächsthema
Im Gespräch mit der Firma wurde schnell klar, dass Sie nur an dem Sensorsystem interessiert sind, wenn die Regelungstechnik der Klimaanlagen mit angeboten wird.

Aussichten
Die Firma ist an eine Kooperation nicht interessiert.

Weitere Kooperationspartner

FRUIT LOGISTICA
Berlin 7. - 9. Februar ***2008***
International Trade Fair for
Fruit and Vegetable Marketing

Die kabellose Sensoren eignen sich besonders gut für die Überwachung bei der Lagerung von Obst, Gemüse und Früchte. Auf der Messe Fruit Logistica 2008 in Berlin ist auch das Thema Logistik- Management ein Thema und deswegen sind internationale Firmen vertreten die ihr technische Know-how zur Logistik vorstellen. Auch das Handling von Obst und Gemüse am Point of Sale im Einzelhandel stellt einen wesentlichen Schwerpunkt dar. Bei der Messe sind noch mehr Firmen vertreten die als Kooperationspartner in Frage kommen.

www.fruitlogistica.de

Landwirtschaftlichen Maschinen

Auf der Landwirtschaftsmesse Agritechnika 2007 wurden mehrere Firmen gefragt ob sie Einsatzgebiete der kabellosen Sensorsysteme bei ihren Produkten sehen.

Firma		**Ansprechpartner**	
	AMAZONEN-Werke H.Dreyer GmbH & Co.KG		Dr.-Ing. Rainer Resch
	Am Amazonenwerk 9-13		
	D 49205 Hasbergen		
Tel:	+49 (0) 5405 501-0	Tel:	+49 (0) 5405-501-362)
Fax:	+49 (0) 5405 501-147		
	www.amazone.de		dr.rainer.resch@amazone.de

Firma		**Ansprechpartner**
	B.Strautmann & Söhne GmbH & Co. KG	Dr. Johannes Marquering
	Bielefelder Str. 53	
	D 49196 Bad Laer	
Tel:	:+49(05424)802-18	
Fax:	+49(05424) 802-75	
	www.strautmann.com	marquering@strautmann.com

Produkte der Firmen
Düngerstreuer, Pflanzenschutzgeräte, Bodenbearbeitungsgeräte und Sämaschinen (Amazone)
Ladewagen, Futtermischwagen (Strautmann)

Gesprächsthema
Beim Gespräch mit der Firma Amazone wurde über die Technik der kabellosen Datenübertragung gesprochen und über mögliche Einsatzgebiete diskutiert, ebenfalls teilgenommen hat Herr Dr. Marquering (Entwicklungsleiter Strautmann).

Aussichten

Die Aussichten über eine Zusammenarbeit zwischen WiSensys und Amazone ist unwahrscheinlich, weil kein Einsatzgebiet für kabellose Sensoren bei den Produkten von Amazone in Sicht ist. Nur für die Entwicklung der Maschinen könnte das System von WiSensys für Amazone interessant sein. Die Firma Strautmann verfügt über weniger Entwicklungskapazität im Bereich Elektronik, ist evtl. aufgeschlossener. Mit beiden Unternehmen werden demnächst von FH-Seite Gespräche zum Ausbau der Elektronik geführt, das Thema 'wireless sensors' wird aufgenommen.

Firma		**Ansprechpartner**	
	Maschinenfabrik Bernard Krone GmbH		Dipl.-Ing. B.Schniederbruns
	Heinrich- Krone Straße 10		
	D 48480 Spelle		
Tel:	+49 (0) 5977-935 0	Tel:	+49(0)5977 935-343
Fax:	+49 (0) 5977-935 339		
	www.krone.de		bernd.schniederbruns@krone.de
			Leiter Entwicklung Elektronik

Produkte der Firma

Scheibenmähwerke, Hochleistungs- Mähaufbereiter, Kreiselzettwender, Kreiselschwader, Ladewagen, Rundballenpressen, Großpackenpressen und Selbstfahrender Feldhäcksler

Gesprächsthema

Im Gespräch mit Herrn Hinsch (Krone) wurde schnell klar, dass er die kabellosen Sensoren nur im Bereich der Entwicklungshilfe als sinnvoll ansieht.

Aussichten

Die Firma Krone könnte eine Demo- Version des Sensorsystems bestellen, um dadurch die Entwicklung der Maschinen zu verbessern.

Firma		**Ansprechpartner**	
	AGROCOM GmbH &Co. Agrarsystem KG		Dr. Michael Quinckhardt
	Potsdamer Straße 211		Geschäftsführer
	D 33719 Bielefeld		
Tel:	+49 (0) 521 2079 0	Tel:	
Fax:	+49 (0) 521 2079 500		
	www.agrocom.com		

Produkte der Firma

Precision Farming, Agrarelektronik, Agrarsoftware

Gesprächsthema

Agrocom ist eine 100%-Tochter von Claas und wird die Einsatzmöglichkeiten zu 'Wireless Sensors' in beiden Unternehmen prüfen. Im Vorfeld dieses Gesprächs wurden bereits Gespräche mit Herrn Dr. Diekhans (Claas, siehe Einsatz des Feuchtsensors beim Mähdrescher) und Herrn Möller (Agrocom) geführt.

Aussichten

Ob es zu einer Zusammenarbeit oder Tests kommt, ist schwer einzuschätzen. Tests mit Claas bzgl. des Feuchtesensors können nach Absprache durchgeführt werden (Diekhans).

Matrix of PMCs and Companies

PMC's - Companies (x potential client, c=competitor)	Storage Computing for storage buildings in boxes or for bulk goods	Climate monitoring (RH, Temp.) in greenhouses	Wireless monitoring on mobile platforms	Mobile platform with trailer as a product	Storage computing for silos	Sensor activated control of distributed equipment in greenhouses	Water and fertilization monitoring in outdoor soil based crops for irrigation	Transport monitoring and logging ('chip in the crate')	Phyto-monitoring (indoor/outdoor)	Water and nutrient monitoring in substrates or potted plants (indoor/outdoor)	Measurement of the climate in an animal barn	Weather-monitoring (outdoor)	Economy & Environment	Storage Ambient Feedback during shipping	Storage computing for storage in the field	Driver assistant for outdoor management	Safety at Work	Organic farming	Shipping conditions of seeds, logging during transport and storage (RH,T)
Agro Partnersss Holland BV						x													
Agro Vent System	x																		
Agrocom/Claas			x	x															
Ailocom																		x	
Amazonen-Werke			x													x			
Ammerlaan Beheer BV		x				x													
Baumer																		x	
B-E de Lier B.V		x				x													
Beemster Elektrotechniek B.V		x				x													
Bernard Krone GmbH Landmaschinen			x	x												x			
Boekestijn Elektrotechniek B.V		x				x													
Bosman Topholding B.V.		x				x				x									
Brinkman Tuinbouw Techniek		x				x				x									
Cogas Zuid B.V.		x				x				x									
Columbia Weather Stations												x							
Crowcon																	x		
Cultilene										c/x									
Dalsem Tuinbouwprojecten B.V		x				x				x									
Decagon							c												
Delta-T Devices							c		c										

Eijkelkamp BV							c		c			c							
Elektrotechniek L.J. van der Laan B.V.		x				x													
GAKON BV		x				x													
Gaugele GmbH	x																		
Genap BV										x									
Grimme			x	x												x			
Grodan										c									
Growlab									c	c									
Handelsonderneming Revaho BV										x									
Honold																		x	
Hoogendoorn Automatisering B.V.		x				x													
Hortilux Schréder B.V.		x				x													
Hortimax B.V.		x				x				x									
Installatiebedrijf W.S. Janssen B.V.		x				x				x									
J. en P. Schouten Installatietechniek BV		x				x													
John Deere			c	x											x	x			
Kandelaar Elektrotechniek B.V,		x				x													
Kassenbouw 't Noorden BV						x													
Keller														x					
Kistler														x					
KUBO Tuinbouwproducten BV						x													
Kuhn			x																
Leen Huisman BV						x													
Lek Installatietechniek B.V.		x				x				x									
Lemken			x																
Let's Grow.com									?										
Leuze																		x	
Ludvig Svensson BV						x													
LXE	x				x														
Metazet Zwethove CV		x				x													
Mooij Geforceerde ventilatie BV	x				x														
Motec																		x	
Netafim									c										

Nic. Sosef B.V.		x				x				x									
NTTEAST																	x		
P.L.J. Bom Holding BV		x				x													
PB Techniek B.V.		x				x													
PB Techniek BV										x									
Pepper&Fuchs																		x	
Pessl	c																		
Pfalztechnik	x														x				
Pfeufer GmbH	x																		
Phytech									c										
Phytools									x										
Priva B.V.		x				x				x									
PRIX Dämm & Klimatechnik	x				x														
Rauch			x																
Schep Verwarmning BV		x				x													
Scherm Ned B.V.		x				x													
Sharp																		x	
SuperTech Agroline	x				x														
Stella Laxhuber GmbH	x				x														
Stevens Water							x												
Strautmann & Söhne GmbH			x																
Strooper Watertechniek BV										x									
Technokas BV		x				x													
UDATA													x						
UP GmbH							x					x	x					x	
Van der Arend Beheer Westland B.V		x				x				x									
Van der Hoeven Groep		x				x				x									
Van Diemen BV		x				x													
Verbakel/Bomkas BV		x				x													
W.K. Crone BV		x				x													
Wilk van der Sande B.V.		x				x													
Yara			x	x															
Zantingh BV		x				x													